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APPLICATION OF A RISK MODEL TO QUANTIFY
RELATIVE RISK OF REMEDIAL ACTIONS

THESIS

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The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

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THESIS

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Acknowledgments

In this vast world of academia, I would like to dedicate this thesis to all my family and friends who have given me love and support in the pursuit of further bettering myself.

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As the old saying goes, "It ain't over 'til the fat lady sings." The fat lady may have not sung, but 'Elvis has left the building.' Thank you.

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Abstract

To properly manage the Installation Restoration Program (IRP) in the future, Air Force remedial project managers (RPMs) need a metric to assist in the selection of remedial alternatives for the safe and effective clean up of waste contamination sites. If the baseline site risk assessment indicates that it is necessary to remediate a waste contamination site, it is important to the RPM that the selection process for remediation alternatives considers the potential human health and ecological risks associated with the proposed remediation process. In some instances, the risks may be significant when compared to the baseline conditions.

The Air Force currently uses the Defense Priority Model (DPM) to assist in setting priorities for funding remedial actions based on the relative risk at IRP sites. The DPM provides a numerical score representing the relative potential risk based on the environmental conditions at a site before remedial actions are taken. This study investigates the applicability of the DPM to calculate the relative risks that would be associated with the remedial alternatives under consideration for remediation of the contamination site characteristics. Furthermore, this study compares the relative risks of the remedial alternatives to the reduction in baseline relative risk from remedial efforts. If the relative risk of a remedial activity is greater than the reduction in relative risk of the contaminated site, a different remedial alternative is desired.

Rescoring the DPM to represent relative risk of a site under remedial action conditions demonstrates that three factors influence the risk value of a remedial action: waste quantity, waste containment effectiveness, and waste concentration. Limits of the waste containment effectiveness factor made it impossible to discern relative risk between similar remedial alternatives. Furthermore, for all cases of contamination sites under remedial conditions, the relative risk of the remedial action was less than the reduction in baseline relative risk due to the improvement in waste containment.

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I. INTRODUCTION

General Issue

"[T]he number of hazardous waste sites on the United States Environmental Protection Agency (EPA) National Priorities List (NPL) exceeds 1,000, and estimates have been made that the number could grow to 2,000. The United States Congressional Office of Technology Assessment (OTA) estimated that the list could reach 10,000, requiring remediation activities well into the 21st century" (Schmelling et al., 1992: 220). These staggering numbers signify the increasing awareness to rectify the past's hazardous waste management practices. In the Air Force alone, only 31% of the 4,859 hazardous waste sites identified at the end of FY93 have been remediated (Raymond, 1994). Air Force remedial project managers (RPMs) are becoming hard pressed to meet the Air Force environmental restoration goal, established by the Chief of Staff of the Air Force in 1990, to restore 10% of hazardous waste sites annually with all sites completed by the year 2000. To justify and properly manage remedial actions in the future, Air Force RPMs need a metric to assist in the selection of remedial alternatives for the safe and effective clean up of waste contamination sites.

Under the Comprehensive Environmental Response, Compensation, and Liability Act process, also referred as Superfund, "public health risk assessments are conducted to evaluate the risks associated with 'baseline' conditions at a site, in the absence of remediation, and are used to evaluate whether remediation of the site is needed" (Edmisten-Watkin, 1991: 293). Remedial alternatives are later evaluated against nine criteria established under the Superfund statute:

1. overall protection of human health and the environment;
2. compliance with ARARs;
3. long-term effectiveness and permanence;
4. reduction of toxicity, mobility, or volume;
5. short-term effectiveness;
6. implement ability;
7. cost;
8. State acceptance; and
9. community acceptance (USAF, 1992a: 5-61).

Selection of the appropriate remedial action for a waste contamination site has typically been driven by cost and/or technical feasibility (Edmisten-Watkin, 1991: 293).

If the baseline risk assessment indicates that it is necessary to remediate a waste contamination site, it is important to the RPM that the selection process for remediation alternatives considers the potential human health and ecological risks associated with the proposed remediation process. In some instances, the risks may be significant when compared to the baseline conditions.

The significance in considering potential human health and ecological risks in the selection of remedial alternatives has been observed in an increasing number of cases in which the remediation of waste contamination sites created public health concerns distinctly different than the risks associated with the baseline conditions (Edmisten-Watkin, 1991: 294). The *Washington Post* reported in their December 24, 1988 edition the case of the Rocky Mountain Arsenal Superfund site where "excessive emissions during excavation forced workers to evacuate the site and caused nearby residents to complain of astringent fumes" (Edmisten-Watkin, 1991: 294). At a number of other Superfund sites, the EPA has rejected remediation actions involving excavation after utilizing public health risk assessment procedures for the remedial process.

There are several advantages to considering public human health and ecological risks prior to adopting a particular remedial alternative. These reasons include:

1. adverse health impacts may occur as a result of exposure to the chemicals during the remediation process,

2. human or environmental exposure to chemicals increases the liability of the potentially responsible party,

3. overall costs may increase, and

4. regulatory concern may be heightened (Edmisten-Watkin, 1991: 294).

Public acceptance of a remedial proposal will minimize if a chemical exposure has the potential to occur. Additionally, these concerns will capture the interest of the media and possibly generate negative media coverage for the site owner.

Research Problem

In conjunction with the baseline site risk assessment performed under The Agency for Toxic Substances and Disease Registry (ASTDR) public health assessment guidelines, the only measures of relative risk performed during the Air Force's Installation Restoration Program are the Department of Defense's Defense Priority Model and the EPA's Hazard Ranking System - used for determining if a site is eligible for the National Priorities List under the Comprehensive Environmental Response, Compensation, and Liability Act. Both methods use baseline site data to determine the relative risk of the existing waste contamination site for purposes of prioritization. There is currently no standard to assist Air Force RPMs in the evaluation and selection of a remedial alternative based on the risk associated with the remediation action (Clendenin, March 1994). To assist RPM's decision making in the selection of safe remedial alternatives, the Air Force needs a management tool to assess relative risks associated with remedial alternatives under consideration.

Research Objectives

The purpose of this study is to develop a metric to assist Air Force RPMs in the selection of a remedial alternative based on the relative risk of the remediation activity.

This study evaluates the application of existing risk assessment techniques to quantify the relative risk of remediation alternatives and select the alternative with the lowest relative risk. Furthermore, it is the purpose of this study to compare the remedial alternative with the lowest relative risk to the reduction in baseline relative risk from remedial efforts. If the relative risk of a remedial activity is greater than the reduction in relative risk of the contaminated site, a different remedial alternative is desired.

Scope and Limitations of Study

The site characteristics that are chosen for purposes of testing the relative risk model are Air Force groundwater sites contaminated with VOCs such as benzene, ethyl benzene, toluene, and xylene - fuels and solvents being the most common contaminants found on Air Force installations (Raymond, 1994). Additionally, groundwater sites are selected because the most common area of concern at sites on the EPA Superfund list is groundwater contamination (Schmelling et al., 1992: 220). Furthermore, the EPA has estimated that VOCs make up 60% of all sites in the intermediate term market (3-5 years) for cleanup (Foley, 1994). The technologies most commonly associated with the clean up actions of the waste site characteristics (i.e., groundwater contamination, landfill, surface impoundment, spill, waste piles) will be applied to the established methodology.

Existing methods for measuring relative risk will be used to demonstrate how they can be used to assess relative risk of a remedial action. It is not the focus of this research to evaluate or validate the methods used to assess risk at IRP sites.

II. LITERATURE REVIEW

The Comprehensive Environmental Restoration, Compliance, and Liability Act

The Air Force established the Installation Restoration Program (IRP) to address the problems of contaminated sites that pose a threat to public health, welfare, and the environment. The Air Force is required to comply with the Comprehensive Environmental Restoration, Compliance, and Liability Act of 1980 (CERCLA), also known as the "Superfund" statute, and the Superfund Amendments and Reauthorization Act of 1986 (SARA). CERCLA addresses the identification, characterization and, when necessary, the cleanup of releases of hazardous substances, pollutants, and contaminants into the environment from inactive hazardous substances sites (Rudolph, 1993: 1-2).

There exists a number of significant differences regarding the CERCLA process as it applies to Federal agencies, such as the DoD, versus non-government entities. First, the DoD, instead of the Environmental Protection Agency (EPA), is the "lead agency" at DoD sites under Executive Order 12580, response action authority delegated by the President. The Executive Order gives Federal agencies, such as the DoD, primary responsibility for seeing that appropriate investigations and response actions are taken at their respective sites. Second, the "lead agency" status gives the DoD sole authority to select remedial actions at all non-National Priority Listed (NPL) sites located on DoD installations. Remedy selection is jointly done by DoD and EPA at NPL sites. Third, Federal facilities, unlike private sector facilities, have an affirmative duty under CERCLA to search for potential CERCLA sites (Rudolph, 1993: 1-9).

Figure 1 illustrates the CERCLA multi-step remedial action process. Any and all remediation actions are initiated by a Discovery and Notification (D&N). Releases are characterized according to information obtained during record searches and release reports pursuant to CERCLA reportable quantities.

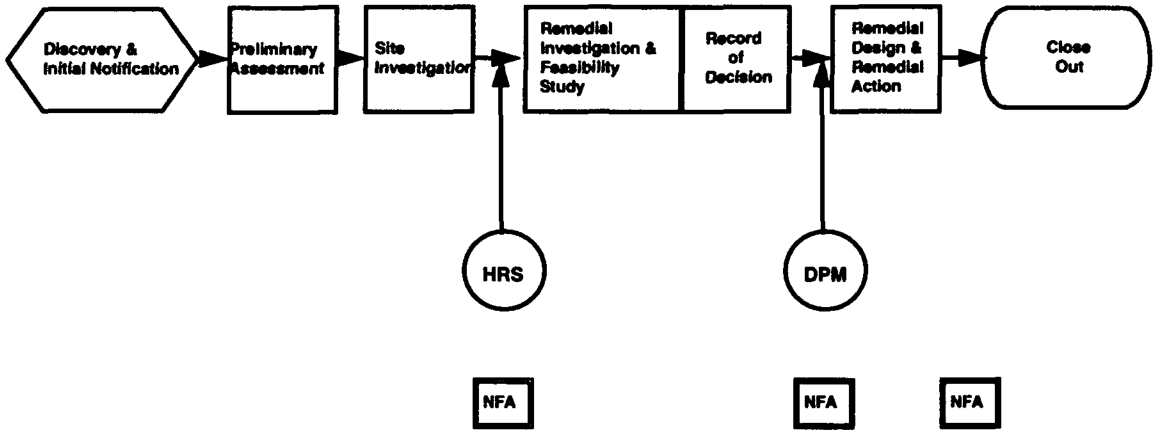


Figure 1. The CERCLA Remedial Action Process (USAF, 1992a: 3-17).

Initial evaluation of existing information begins with the Preliminary Assessment (PA). Its purpose is to determine whether further study is required at the release site. The PA describes the source and nature of release, evaluates threats to the public health and welfare and environment, and, pending a no further action (NFA) decision, recommends subsequent steps required in the remedial action process (USAF, 1992a: 1-4).

The third step is the Site Inspection (SI). Remedial SI involves the sampling of soil, groundwater, and surface water, as required by conditions of the release. The report required at the end of the investigation describes known contaminants at the site, migration pathways for the contaminants, and receptors at or near the end of the site. If, at the conclusion of the SI, it is determined that all three conditions do not exist, the site may be eliminated from further consideration. However, if it is determined that a site may pose a threat to human health or the environment and a remedial action may have to be taken, a Remedial Investigation/Feasibility Study should be undertaken. Information gathered during the SI is provided to the EPA and is used to evaluate relative risk of the release under the EPA's Hazardous Ranking System (HRS). Sites with a score of 28.5 or greater are placed on the National Priorities List (NPL), EPA's list of the countries most contaminated sites. (Rudolph, 1993: 1-5).

The Remedial Investigation (RI) determines the nature and extent of the contamination and the nature and extent of the threat to human health and environment. In the RI, a comprehensive sampling and analysis plan is prepared and enacted to insure enough data is generated to make decisions about site and waste characteristics, potential hazards, and applicable treatment options (USAF, 1992a: 1-5). In conjunction with the RI, remedial action alternatives are developed and screened in the Feasibility Study (FS) to address the threats to human health and environment. The National Contingency Plan (NCP) requires the establishment of remedial action objectives and remediation goals in the development of remedial alternatives (Rudolph, 1993: 1-6). At the conclusion of the RI/FS stage, a Record of Decision (ROD) is made in the selection of the remedial alternative. Note, a no further action (NFA) decision is a viable remedial alternative.

The site information gathered during the PA/SI and RI/FS process is used to score the site using the DoD developed system, called the Defense Priority Model (DPM). The DPM uses relative risk to prioritize all remedial actions under consideration at DoD IRP sites. Priority is given for Remedial Design/Remedial Action funding based on relative risk of the site. The purpose of DPM is to address funding towards the "worst first." It would be to a RPM's advantage, at this stage in the CERCLA process, to have a management tool at their disposal to assist in the selection of a remedial alternative by using a methodology, such as the DPM, to compare the relative risks associated with the various remedial alternatives under consideration. The purpose of this study is to provide such a tool.

The last stage of the remedial action process, before Close Out, is Remedial Design/Remedial Action (RD/RA). The RD/RA stage is the execution stage of CERCLA. The RD includes establishing information requirements, obtaining design information from the base, and discussing the design concept with a contractor (USAF, 1992a: 1-6). The RA is the implementation of the cleanup technology.

"Site Closure" is the final point in the CERCLA process when the regulatory authority no longer considers a site to be a threat to human health or the environment.

Risk Assessment

As can be seen, the CERCLA remedial action process, described above, relies heavily on risk assessment for the prioritization of clean-up actions based on the relative threat to human health and environment. Risk assessment provides the scientific data necessary for making risk management decisions (Masters, 1991: 191). In its broadest sense, risk assessment is defined as "the strict technical assessment of the *nature* and *magnitude* of risk" (Shelley, 1993: 3). There are a variety of purposes, applications, and methods for assessing risks to human health and the environment throughout the CERCLA process. The various applications include both qualitative and quantitative methods to describe risk. Two risk measurements utilized in the CERCLA process are quantitative risk assessments and relative risk models (Edwards, 1992: 7).

Quantitative Risk Assessment. Quantitative risk assessments are used in the estimation of excess risk or adverse impacts of contaminants to exposed populations and the environment (Edwards, 1992: 7). Risk assessments involve four steps: hazard identification, dose-response assessments, exposure assessments, and risk characterization (Shelley, 1993: 23). Results of risk assessments focus on probability of failure (release) and severity of an adverse response to an exposure of a contaminant (Shelley, 1993: 43).

The Agency for Toxic Substances and Disease Registry (ASTDR) has established public health assessment guidelines for assessing excess risk. However, a variety of inferences can be made from the data at each site and the interpretation of the ASTDR guidelines. Methods currently used for quantitative risk assessment are controversial within the field of environmental management. Quantitative risk assessments require consolidating highly uncertain, conflicting, and complex , if not ambiguous, data (Shelley, 1993: 6). The results are inferred from data that is "extrapolated well beyond anything actually measured" to a value that represents the excess risk to a certain population (Masters, 1991: 191). The controversial nature of the science of risk assessment as well as public concern, economic benefit, and political influence has made it difficult to use as a consistent method for quantitative risk assessment (Shelley, 1993: 7).

Relative Risk Assessment. Relative risk assessment is a derivative of comparative risk analysis. Comparative risk analysis is a procedure for ranking environmental problems by their seriousness (relative risk) for purposes of assigning priorities. Typically, a problem is classified by it's type of risk - cancer, noncancer, health, ecological effects, and so on. The relative risk of a problem is then used as a factor in determining what priority the problem should receive. (Cleland-Hamnett et al., 1993: 19)

The principal components of EPA's Superfund program, set forth in CERCLA/SARA legislation, required EPA to develop a system to assess the relative degree of risk to human health and the environment at potentially uncontrolled release sites (Rudolph, 1993: 4-2). The EPA developed the HRS to quantify the relative threat associated with actual or potential releases of hazardous substances. The HRS is EPA's primary screening tool for determination of placement of a site on the NPL. Additionally, it establishes a prioritized list of sites for further investigation and response actions under CERCLA (USEPA, 1992: 1).

As was previously mentioned, the HRS uses data generated during the PA/SI phases of the CERCLA remedial action process. The HRS is designed to be a simple numerical model that assigns a score from 0 to 100 based on:

1. The likelihood that a site has released or has the potential to release contaminants into the environment (or , for the soil exposure pathway, likelihood of exposure).

2. The characteristics of the waste (toxicity and waste quantity).

3. The people or sensitive environments affected by the release. (USEPA, 1990: 1)

Any site scoring 28.50 or greater is eligible for the NPL.

The Defense Priority Model, used by the Air Force, evolved from the Air Force Hazard Assessment Risk Model (HARM), a relative risk model which was used in the early 1980s to identify IRP sites based on initial investigations conducted at potential sites. The DPM was developed to assist Air Force and DoD managers as a tool to aid in making funding decisions (USAF, 1992b: 1). The DoD chose not to adopt the EPA's HRS model, but develop their own, for three reasons:

1. the HRS evaluation is done on a base-wide basis instead of by site;
2. the HRS is time intensive; and
3. the HRS is not as good of a model as the DPM in determining relative risk of sites since it is compared to a threshold of 28.5; any site below 28.5 is not considered on the NPL and is dropped for prioritization (Edwards, June 1994).

Sites prepared for remedial action, under the Air Force Installation Restoration Program, are prioritized by the DPM risk score for procurement of remedial action funding. The DoD policy is to address the worst sites first.

The DPM is applied after extensive site specific data has been collected during the PA/SI. The data is used to generate a score indicating the relative risk of the site to human health and the environment (USAF, 1992b: 1). As it is with the EPA's HRS methodology, the DPM calculates relative risk by considering:

1. The characteristics, concentration and mobility of contaminants found at the site (hazards).

2. The potential for contaminant transport through the environment (pathways).

3. The presence of potential target populations (receptors). (USAF, 1992b: 1)

All three must be present to score the risk present at a site. If any one of the three parameters is missing, risk at the site will not be present.

The DPM is considered a tool in Air Force environmental management. Management decisions are made using the DPM score in conjunction with additional information such as mission impact, community concerns, regulatory considerations, and program efficiencies.

Short-term vs. Long-term Risk. Evaluation of human health risks associated with proposed remedial actions has generally been qualitative in nature, even though the EPA guidance document for conducting RI/FS indicates that remedial alternatives need to be evaluated against both short-term and long-term risks (Edmisten-Watkin et al., 1991: 293). The EPA's Risk Assessment Guidance for Superfund: Volume I - Human Health Evaluation Manual (Part C, Risk Evaluation of Remedial Alternatives) (RAGS) provides necessary guidance in the conducting of quantitative risk evaluations for remedial alternatives. The following synopsis of short-term and long-term risk is found in the RAGS.

Long-term human health risks associated with a remedial alternative are those risks that exist from residuals created from the remediation action and those risks that remain from the incomplete removal of contaminants from the site, or, in more appropriate terms, the technology's capability of meeting preliminary remediation goals (PRGs) (1991: 14). Long-term human health risks are considered those risks that remain after the remediation action is completed.

For the majority of risk evaluations, it is sufficient for the analysis to simply indicate whether an alternative has the potential to achieve the PRGs or not. However, if more detail is required for assessment of long-term risk associated with a remedial alternative, it may be useful to compare remedial alternative's capabilities of achieving PRGs, whether one may be able to surpass PRGs, or whether one may be able to accomplish the goal in a shorter time frame (1991: 14).

In addition, consideration for long-term human health risks must also be given for remedial technologies that may degenerate existing contaminants into new contaminants of concern that were not present at the site before remedial actions were implemented (1991: 9). A RPM will be required to evaluate the risk associated with the new substances.

Short-term health risks are generally associated with the existing baseline risk of the contaminant site, established in CERCLA PA/SI phase, plus any new risks that would occur while implementing the remedial action. Short-term risk exists during the lifetime of the remedial action and involves the evaluation of potential short-term risk to: (1) neighboring populations, and (2) onsite workers associated with the remediation (1991: 15). Figure 2 illustrates the short-term and long-term risk factors associated with a remedial action.

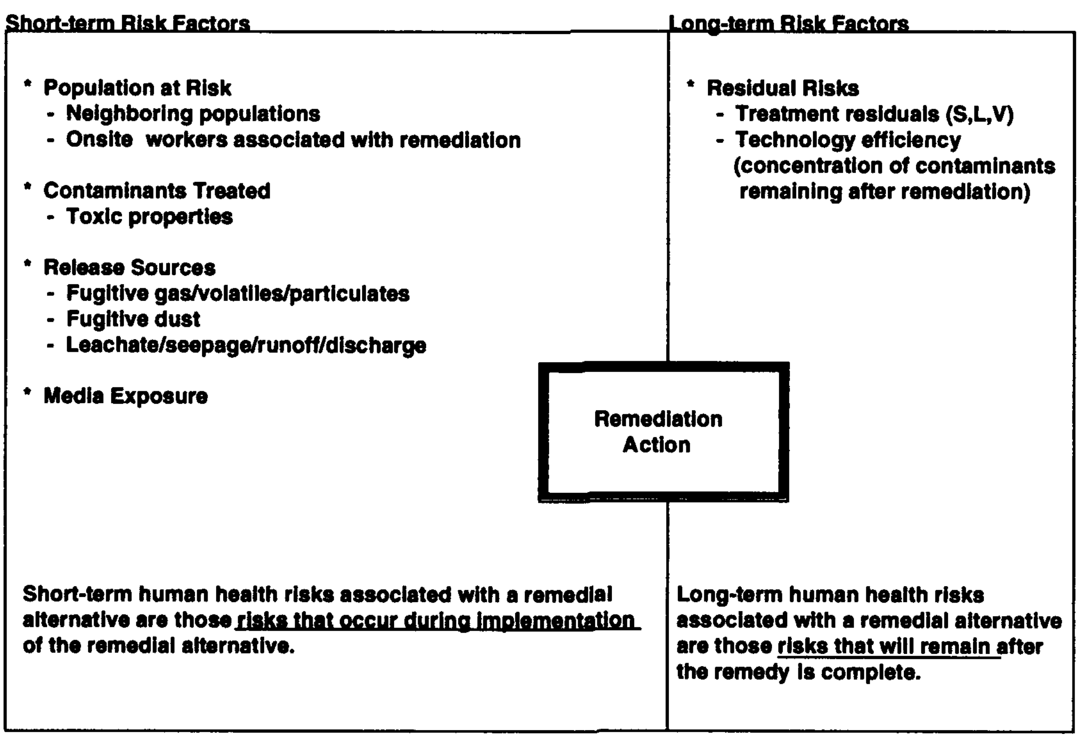


Figure 2. Factors Driving Relative Risk of a Remedial Action

Potential Significant Releases

The important difference between the baseline site risk assessment and the risk evaluation of the remedial alternative involves the exposure sources (1991: 16). The untreated site contamination is the source of exposure for the baseline risk assessment; whereas, for remedial alternatives, the potential sources of exposure are those releases that occur from implementation of remedial technologies. Figure 3 illustrates an example of an exposure for the pump and treat remediation of groundwater contaminated with volatile organic compounds (VOCs) such as benzene, ethyl benzene, toluene, and xylene (BETX) - compounds found in petroleum products. With the understanding that an alternative water source is provided to the population affected by the contamination, Figure 3 depicts how fugitive VOCs, released into the air medium, are carried by prevailing winds to the nearby population. As a consequence, failure to completely capture VOCs through air stripping leads to a short-term human health risk not previously present.

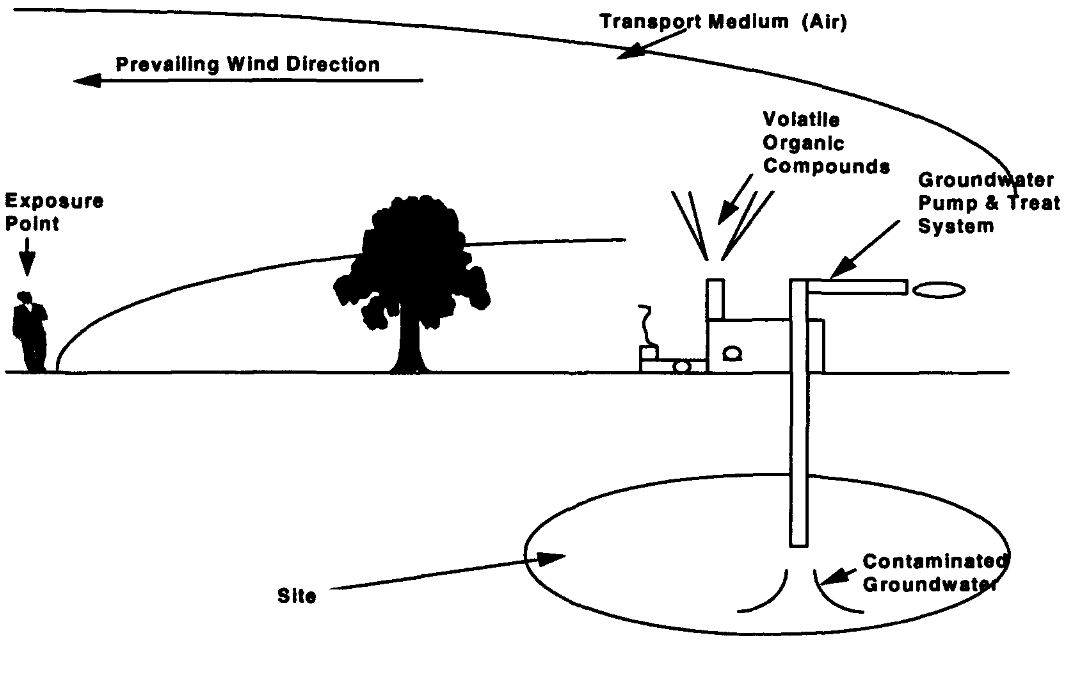


Figure 3. Illustration of an Exposure Pathway for Remedial Action.

Appendix A provides a listing established by the EPA of all potential significant releases associated with each remediation technology on pages 52 to 56. The primary potential significant releases associated with the air medium are fugitive emissions of particulates and/or VOCs and stack emissions containing VOCs, metals, particulates, and products of incomplete combustion. Primary potential significant releases associated with the groundwater medium, in general, are seepage and leaching, but they can also contaminate surface water. Runoff and discharge are potential significant releases associated with surface water, however, they may also contaminate groundwater. Other potential significant releases that may be associated with a remedial action are seepage or runoff to nearby soil, disposal of ash and other solid residues, disposal of sludge residues, disposal or regeneration of spent activated carbon, possible solvent residuals in treated soils, and disposal of backwash or cleaning residues. (1991: 37-41)

III. METHODOLOGY

This study investigates the use of an established risk model to determine the applicability of establishing the relative risks associated with remedial actions for purposes of selecting the remedial alternative with the lowest relative risk. The purpose of remedial actions at IRP sites typically involves reducing the volume of the contaminants and/or limiting the potential for the contaminants to be transported. However, the remedial action itself may also create, or increase, the potential for contaminants to be transported to a medium through release mechanisms not present under baseline conditions.

As remedial operations are put into action and progress is made towards cleaning up a site, the various factors used to measure risk change. A current risk model used in the IRP process to measure risk was selected to asses the relative risk of contaminated sites under remedial conditions. The model selected should reflect changes in the environmental risk of a site as inputs for contaminant levels, transport pathways, and physical site characteristics are influenced by the remedial action.

To evaluate the model's application as a tool to assess the relative risk of a remedial action, two investigative objectives were carried out:

1. Identify the input variables to the model that can be changed or affected by the remedial action.
2. Rescore sample Air Force sites by changing the variable input parameters to reflect environmental conditions under a remedial action.

The purpose of rescoring the Air Force sites was to investigate the model's sensitivity to the input parameters that can be altered by the remedial action. Furthermore, it was desired to investigate the sensitivity of the model's scores to the varying site characteristics found at each base, and each individual site thereon. The intent of this effort was to determine if the risk of a remedial action can be measured with the model. The scores of the selected Air Force sites were compared against each other to evaluate patterns associated with the three components of the risk model - pathway parameters, contaminant hazard parameters, and receptor parameters. It was not the focus of this research to validate the methods used by the model selected to calculate risk at contaminated sites.

Once the risk model was selected, sample Air Force IRP sites were chosen to measure the risk of an established (constant spill characteristics) contaminated site under remedial conditions. The sample IRP sites were chosen from sites where environmental conditions had previously been assessed using the selected risk assessment model. Furthermore, it was desired to choose sites that would fairly represent the different geographical conditions existing throughout Air Force installations. Each site was rescored by changing the variable input parameter(s) under consideration to reflect the environmental site conditions during remediation.

The following chapters go into more detail of the methodology performed for this research. Chapter IV describes the scoring methodology of the model selected. The methodology performed to identify the input parameters influenced by remedial actions is described in Chapter V, and results and analysis of the model's application to remedial actions is discussed in Chapter VI.

IV. QUANTIFICATION OF RELATIVE RISK OF REMEDIAL ACTION

Introduction

The DPM is used by the Air Force and DoD to prioritize IRP sites for remedial action based on the relative risk to human health and the environment. The application of DPM to measure relative risk of a remedial action will be investigated. The DPM was selected for this research because the Air Force currently uses the model to assess the relative risk of all IRP sites ready for the RD/RA phase and not just those for NPL considerations. Additionally, the DoD believes that DPM provides a rational methodology for indicating a site's relative risk to human health and the environment and has established this risk-based approach as an operating principle in Federal Facility Agreements for site cleanups with the EPA, and in Defense and State Memoranda of Agreement's (USAF, 1992b: 1). The following detailed description of DPM is referenced from pages 21 to 30 of Edwards' 1992 thesis and describes how the model is used to measure the relative risk of a remedial action.

Defense Priority Model (DPM)

As was previously mentioned in the literature review, the DPM was developed to assist Air Force and DoD managers in establishing priorities for funding remedial actions at IRP sites. The DPM provides a method to generate a score from data collected during the PA/SI and RI of an IRP site and rank the potential threat to human health and the environment. The DPM score provides a common measuring stick within the Air Force which represents the relative environmental risk of a site (Clendenin, 18 May 94). The following is a brief discussion on the history of the development of the DPM and an explanation of the methodology used to calculate relative risk scores for IRP sites.

History. Work began on the modern day DPM methodology in 1984 when the Air Force recognized the need for a defensible methodology for ranking hazardous waste containing sites in need of cleanup. The basic philosophy and methodology was initially developed for the Air Force Hazard Assessment Risk Model (HARM). The HARM was used during the site identification stages of the IRP to evaluate potential sites for further consideration in the cleanup process. An arbitrary HARM score was chosen to delineate which potential sites would be identified as IRP sites and continue with the cleanup program (1992: 22). The original HARM model was then evaluated and tested extensively by a number of reviewers and the results led to significant modifications and the development of HARM II (USAF, 1992b: 9).

HARM and HARM II were developed for the Air Force under an interagency agreement with Department of Energy at the Oak Ridge National Laboratory (USAF, 1992b: 9). The algorithms and inputs for the model were initially encoded using expert systems technology, but limitations to the expert systems required adaptation of the model to a computerized Artificial Intelligence (AI) application software (USAF, 1992b: 10).

In 1987, the EPA reviewed HARM II along with several other site rating models to determine a starting point for revisions in their HRS. Their decision was to continue to develop HRS; however, they were able to identify shortcomings in the HARM II that led to further revisions in the model. In November of 1987, the Secretary of Defense proposed use of the model for ranking DoD sites for remedial action under the Defense Environmental Restoration Program (DERP). HARM II was renamed DPM and DoD continued with the development of the model. (USAF, 1992b: 9-10)

DoD formally announced their intentions on using the model to establish a risk based priority for allocation funds in the Federal Register and solicited comments on the HARM II methodology. Comments were received from the Association of State and Territorial Solid Waste Management Officials, three states, and the EPA. A formal response was provided by DoD and the comments were incorporated into DPM (USAF, 1992b: 3). The first version (Version 2.0) of the DPM was released for use by DoD in

1989. Inputs have been actively sought on an annual basis from the Military Services as well as from individual users. Version 3.0 and Version FY92 have subsequently been released to incorporate additional comments received from EPA and the states during their review of the earlier versions (1992: 23). Additionally, the FY94 (Quick DPM) is just being released to AF installations at the time of writing.

DPM Methodology and Structure. The DPM provides a numerical score representative of relative risk. The relative risk score is a function of three factors: the characteristics, concentration and mobility of contaminants found at the site (**hazards**), the potential for contaminant transport through the environment (**pathways**), and the presence of potential target populations (**receptors**). All three must be present to score a site (USAF, 1992b: 1). The DPM is made up of three segments to address each factor addressed above. Scores are first generated within each segment. Subscores are then calculated for each of eight combinations of potential transport pathways and potential receptors (ODASD(E), 1992:1). The final score is calculated by weighing and combining the subscores using a weighted root-mean-square algorithm (ODASD(E), 1992: 133).

The methodologies for scoring each segment of the DPM are briefly discussed below. The segments are described in the order in which data is input into DPM. First, the pathway segment is scored. Second, contaminant hazard scores are calculated for each pathway; and finally, the potential receptors segment is scored. Figure 4 illustrates the methodology used to calculate the DPM score for a site. The final section provides a description of the algorithm used for the computation of the final score. The complete algorithm for calculation of a DPM score is provided in Appendix B on pages 57 to 68.

Scoring Pathways. The pathways portion of the DPM methodology rates the potential for contaminants from a waste site to enter each pathway. Four contaminant transport pathways are considered by the model. The pathways are surface water pathway, groundwater pathway, air/soil volatiles pathway, and air/soil dust pathway. A

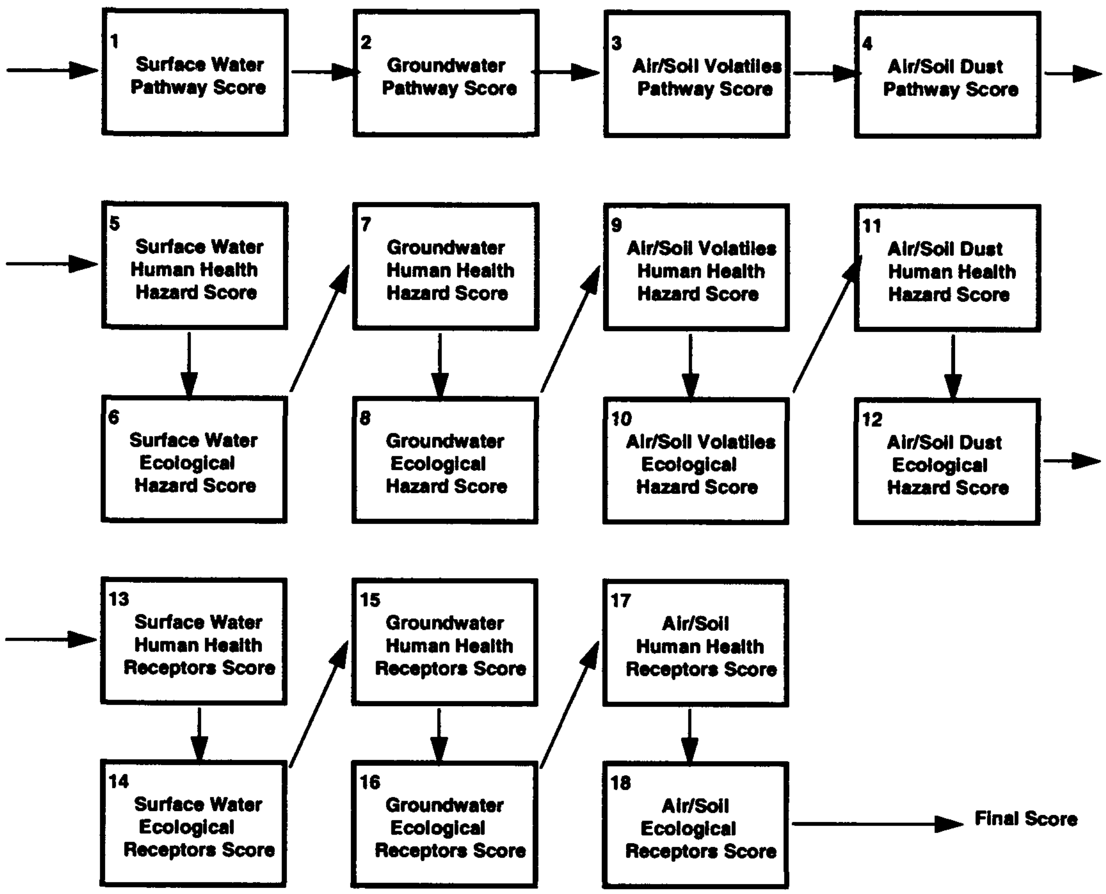


Figure 4. DPM Model Segments and Scoring Order (USAF, 1992b: 2).

separate score is calculated for each pathway; the higher of the two air/soil pathway scores is used in the final computation (USAF, 1992b: 2).

Three components of information regarding conditions existing at the waste site are used to calculate each pathway score. The first type of information relates to the potential for contaminants to enter the pathway given the physical characteristics of the pathway (USAF, 1992b: 2). Various input parameters for each of the four pathways indicate the relative potential for the contaminant to enter the respective pathways (ODASD(E), 1992: G1-G4). The second component is the "waste containment effectiveness factor." This factor "adjusts the pathways score to account for the effectiveness of engineered barriers or clean-up actions in reducing the potential for contaminant transport along a particular pathway" (ODASD(E), 1992: 26). Values range from 0.1 to 1.0 with a 0.1 signifying optimum containment and a 1.0 signifying little or no effective containment (ODASD(E), 1992: 26). The third component is the amount of contaminant(s) present or the "waste quantity factor" associated with the site (ODASD(E), 1992: 26).

The DPM uses two different methodologies for scoring each pathway depending on whether there has been a detected release (measured) or a non-detected release (potential) of a contaminant(s) into the respective pathway. If a detected release is observed in a transport medium, the potential for the contaminant(s) to enter the respective pathway is scored a 100 (maximum normalized score). The input parameters for the physical characteristics of the pathway are then skipped for the case of a detected release because the potential is established as 100%. The scores for the waste containment effectiveness and waste quantity factors are summed and normalized to provide the overall score for the pathway (ODASD(E), 1992: G1-G4).

Non-detected releases are established based on the absence of chemical data. The input parameters to the physical characteristics of the pathway are used to score the potential for a contaminant to enter the pathway. The resulting characteristic score is normalized and then multiplied by the normalized sum of the waste containment effectiveness and waste quantity factors to provide the overall score for the pathway (ODASD(E), 1992: G1-G4). A copy of the algorithm for scoring the pathways segment of the DPM by hand is located in Appendix B.

Scoring Contaminant Hazard. The contaminant hazard scoring segment of the DPM rates the human health hazards and the ecological hazards of the identified contaminant(s) at the site. Eight separate hazard/pathway scores are calculated:

1. human health hazards of surface water contaminants,
2. ecological hazards of surface water contaminants,
3. human health hazards of groundwater contaminants,
4. ecological hazards of groundwater contaminants,

5. human health hazards of air/soil volatile contaminants,
6. ecological hazards of air/soil volatile contaminants,
7. human health hazards of air/soil dust contaminants, and
8. ecological hazards of air/soil dust contaminants. (ODASD(E), 1992: 71)

The DPM calculates hazard/pathway scores differently depending on whether a contaminant has been detected (measured) for the respective pathway. For media in which contamination has been detected, the concept of Average Daily Intake (ADI) is used for scoring human health hazards. The detected concentration of a contaminant is first converted to a daily intake and then divided by the benchmark ADI for the contaminant. A quotient is calculated for each contaminant and then summed to provide a score for the surface water and air/soil pathways. A hazard quotient greater than one is considered to represent a threat. The same procedure applies to the groundwater pathway, but the quotients, in this case, are divided by derived retardation factors calculated for the respective contaminants and then summed to provide the human health hazard score (ODASD(E), 1992: 71).

An analogous procedure is used for the calculation of detected ecological health hazards. The observed concentrations are divided by appropriate benchmark concentrations for ecological receptors in the respective pathways and the quotients are summed (ODASD(E), 1992: 71).

All contaminants known to be present at a site are considered in calculating the total human health and ecological hazard scores for both surface water and groundwater pathways. According to the DPM user's manual, a contaminant is known to be present at a site if:

1. it is a principal component of the materials that were placed or spilled on the site,

2. it has been detected in a chemical analysis of site soils at a level that represents an increase above background, or

3. it is visible at the site, but no determination of concentration has been made. (ODASD(E), 1992: 82, 92)

For media in which contamination has not been detected, human health hazard scores are calculated based on the maximum ADI. Ecological hazard scores are calculated based on the benchmarks for toxicity for the appropriate ecological receptors (ODASD(E), 1992: 71). The contaminant hazard scores are set to zero for no detectable concentrations of contaminants for the air/soil volatile and air/soil dust pathways (ODASD(E), 1992: G-7, G-8).

Scoring Receptors. The receptors portion of DPM rates the potential for human and ecological resources to be exposed to contaminants released from a waste site. The model calculates scores for six types of receptors:

1. human health receptors of surface water contaminants,
2. ecological receptors of surface water contaminants,
3. human health receptors of groundwater contaminants,
4. ecological receptors of groundwater contaminants,
5. human health receptors of air/soil contaminants, and
6. ecological receptors of air/soil contaminants (ODASD(E), 1992: 109).

The human health and ecological receptors for the air/soil pathway are scored only once for both the air/soil dust and air/soil volatile pathways (ODASD(E), 1992: 109). Factors such as the size and proximity of nearby populations and use of surface and groundwater are considered in human health scoring. The proximity of critical habitats and/or sensitive populations is used for ecological receptor scoring (USAF, 1992b: 2).

Combining Segment Scores. The pathway, hazard, and receptor scores for each pathway-hazard-receptor combination are multiplied to generate eight subscores. The products of each segment score are normalized to a 100-point scale and equally weighted (ODASD(E), 1992: 133). Figure 5 provides the algorithm for calculation of the eight subscores. The most conservative subscore between the human health subscore and ecological subscore for both the air/soil volatile and air/soil dust scores is used for the final human health and ecological air/soil pathway scores (ODASD(E), 1992: G-12).

Surface Water Human Health Score	= Surface Water Pathway Score	X Surface Water Human Health Hazard Score	X Surface Water Human Receptor Score	/10,000
Surface Water Ecological Score	= Surface Water Pathway Score	X Surface Water Ecological Hazard Score	X Surface Water Ecological Receptor Score	/10,000
Ground Water Human Health Score	= Ground Water Pathway Score	X Ground Water Human Health Hazard Score	X Ground Water Human Receptor Score	/10,000
Ground Water Ecological Score	= Ground Water Pathway Score	X Ground Water Ecological Hazard Score	X Ground Water Ecological Receptor Score	/10,000
Air/Soil Volatiles[1] Human Health Score	= Air/Soil Volatiles Pathway Score	X Air/Soil Volatiles Human Health Hazard Score	X Air/Soil Volatiles Human Receptor Score	/10,000
Air/Soil Volatiles[2] Ecological Score	= Air/Soil Volatiles Pathway Score	X Air/Soil Volatiles Ecological Hazard Score	X Air/Soil Volatiles Ecological Receptor Score	/10,000
Air/Soil Dust[1] Human Health Score	= Air/Soil Dust Pathway Score	X Air/Soil Dust Human Health Hazard Score	X Air/Soil Dust Human Receptor Score	/10,000
Air/Soil Dust[2] Ecological Score	= Air/Soil Dust Pathway Score	X Air/Soil Dust Ecological Hazard Score	X Air/Soil Dust Ecological Receptor Score	/10,000

[1] The higher of these two scores is used in the final computation.
[2] The higher of these two scores is used in the final computation.

Figure 5. Algorithm to Calculate DPM Scores (Edwards, 1992: 28).

Calculating the Final Score. The six pathway-receptor subscores are combined for the final score. The surface water-human health, groundwater-human health, and air/soil-human health subscores are weighted five times more than their respective ecological receptor subscores. These weighing factors " reflect the general indication of concern in national environmental regulatory policy regarding the relative importance of human health versus ecological risks." (Edwards, 1992: 29)

The weighted root-mean-square algorithm is used to obtain the final relative risk score for the site:

$$S_f = \frac{[5(S_{s,h})^2 + (S_{s,e})^2 + 5(S_{g,h})^2 + (S_{g,e})^2 + 5(S_{a,h})^2 + (S_{a,e})^2]^{1/2}}{4.24}$$

where Sf = overall site score and $S_{s,h}$, $S_{s,e}$, $S_{g,h}$, $S_{g,e}$, $S_{a,h}$, and $S_{a,e}$ = scores for the surface water-human health, surface water-ecological, groundwater-human health, groundwater-ecological, air/soil-human health, and air/soil ecological pathway-receptor combinations (ODASD(E), 1992: 133).

The root-mean-square methodology is an exponential algorithm. When a score for a single pathway-receptor is high, the algorithm will subsequently result in a high score. If additional subscores are high, the final score will increase, but not linearly. This methodology increases the importance of a single high pathway-receptor subscore on the final risk score (Edwards, 1992: 29).

V. MEASUREMENT OF RELATIVE RISK OF REMEDIAL ACTION

As remedial operations are put into action and progress is made towards cleaning up a site, input parameters to the DPM related to the volume, containment, and potential transport of the contaminants will change. The DPM score should reflect a change in relative risk as inputs for contaminant levels, containment effectiveness, and transport pathways are effected.

Six Air Force IRP sites were selected as sample sites for this study. Each site was selected to represent different geographical conditions present at installations throughout the United States. Site 1 was chosen from an installation in the Midwest, Site 2 was chosen from an installation located in Alaska, Site 3 was chosen from an installation located at a high elevation, Site 4 was chosen from an installation located in the Southeast near a large body of water, Site 5 was chosen from an installation located in the Southwest, and Site 6 was chosen from an installation located in the Northwest. These installations were selected because the site inputs used to generate the scores were reviewed by Engineering-Science, Inc., contracted by HQ USAF/CEVR for the scoring of Air Force IRP sites using DPM. Engineering-Science, Inc., with permission of HQ USAF/CEVR, provided the installation data for the sample sites used in this research. The sample sites were scored using the latest version of the automated DPM (ADPM94), provided by 645 ABW/EMR, Wright-Patterson AFB.

To evaluate the DPM's application as a tool to assess the relative risk of a remedial action, two investigative objectives were carried out:

1. Identify the input variables to the DPM that can be changed or affected by the remedial action; and
2. Rescore the six selected Air Force sites by changing the variable input parameter(s) to reflect environmental conditions during a remedial action.

Identify Inputs That Can Be Changed. The DPM has approximately 100 input parameters to calculate a risk score for an IRP site. The first step was to examine the input parameters as they are separated into the three components of the risk model - pathway parameters, contaminant hazard parameters, and receptor parameters.

Pathway Parameters. The pathway parameters can be separated into two categories. The first category is parameters that cannot be affected by remedial actions. Examples of these parameters include input values related to the climate, demographics, and geology of the site. It is expected that the uniqueness of the physical characteristics for each site will cause the DPM score to vary from one site to another for sites with similar contaminant conditions. The second category of pathway parameters is those parameters that can be affected by remedial actions. These parameters include the surface erosion potential and flooding potential for the surface water pathway, and the site activity for the air/soil dust pathway.

For scoring the flooding potential at a site, the DPM user's manual states that the "[f]looding potential is a measure of the potential for contaminants to be transported by flood waters. Flooding potential is determined by the frequency of inundation due to: stream flooding, coastal flooding, high lake levels, or other causes" (ODASD(E), 1992: 25). It is assumed that the flooding potential refers to the site's location in a flood plain. Since regional flood plains would likely not be changed by remedial activities this would not allow changing the input for the flooding potential. However, remedial measures could be taken to eliminate the potential for contaminants to be transported as a result of flooding. Therefore, for this research the input for flooding potential for the rescored sample sites was set to the lowest potential for contaminant transport as a result of flooding.

In addition to the site physical characteristics, two other components are important in the calculation of the pathways segment score of the DPM - the waste containment effectiveness factor for each pathway and the waste quantity factor. The waste containment effectiveness factor "adjusts the pathways score to account for the effectiveness of engineered barriers or clean-up actions in reducing the potential for contaminant transport along a particular pathway" (ODASD(E), 1992: 26). Values range from 0.1 to 1.0 with a 0.1 signifying optimum containment and a 1.0 signifying little or no effective containment (ODASD(E), 1992: 26). It is expected that containment will be the critical factor in the calculation of relative risk for a remedial action. If the remedial activities lesson the effectiveness of containment at a site, it is highly possible that the risk of the remedial activity will be greater than the risk of the baseline contamination site. Appendix C provides a complete listing on pages 69 to 83 of the waste containment effectiveness factors of the four pathways for each waste type.

The third component is the amount of contaminant(s) present or the waste quantity factor associated with the site. The amount of waste present can greatly affect the risk posed by a site. The quantity of the waste is estimated using the measures provided in the waste quantity factors tables, located in Appendix C, for all site types other than landfills. The waste quantity values for sites affected by a spill are:

Quantity of Waste	Score
< 2,000 gal	0.1
2,000 to 10,000 gal	0.3
> 10,000 to 50,000 gal	0.7
> 50,000 gal	1.0 (ODASD(E), 1992: 33).

The waste quantity does not have to be precisely measured; the goal of the DPM is to differentiate between a small, moderate, or large amount (ODASD(E), 1992: 26).

Hazard Parameters. The contaminant hazard scoring segment of the DPM rates the human health hazards and the ecological hazards of the identified contaminant(s) at the site for each of the four pathways. Scoring human health hazards is done using the concept of Average Daily Intake. Ecological hazard scores are calculated based on the benchmarks for toxicity for the appropriate ecological receptors. As was mentioned above in the pathway parameters, not only does the amount of waste present affect the risk posed by a site, but also the concentration and toxicity of the waste. This research will examine the effect the presence of carcinogen and non-carcinogen contaminants have on the DPM score and will further examine the effect of varying their concentrations.

Receptor Parameters. Receptor parameters are similar to the pathway parameters in that they can be separated into two categories. The first category is parameters that cannot be affected by remedial actions, but will make an impact on the site score due to the uniqueness of each site. These parameters include such factors as importance/sensitivity of biota/habitats, groundwater travel time to supply wells and surface water, and populations within 4 miles of the site. The second category is the receptor parameters that can be affected by remedial actions. Such parameters include population drinking from surface water and population potentially at risk from groundwater contamination.

Rescore IRP Sites. The purpose of rescoring the Air Force sites is to investigate the DPM's sensitivity to the input parameters that can be altered by the remedial action and to investigate the sensitivity of the DPM's scores to the varying site characteristics found at each base, and each individual site thereon. Each site was rescored by changing the variable input parameters to reflect environmental conditions under remedial action. Each variable was changed to the most accurate environmental condition considered by the DPM for the parameter under remedial conditions.

A contamination site scenario was selected for purposes of sensitivity analysis of the DPM to the variables changed by the remedial action at the six different geographical locations. Groundwater contaminated with 8,300 gallons of JP-4 was selected as the baseline contamination site characteristics to be held constant for all six sample sites. Since the objective of this research is to investigate the relative risk of remediation of groundwater contaminated with petroleum products, the original site DPM score was modified to account for only BTEX contaminants located in the groundwater and soil . To take into consideration the potential fugitive emissions of VOCs associated with groundwater remediation technology, the air/soil volatiles pathway with a detected release of BTEX in the soil was computed with a maximum waste containment effectiveness factor (0.2). This was required to maintain an air volatiles consideration in the final relative risk score. Failure to score a reportable release in the air/soil volatiles or air/soil dust pathways will zero the relative risk from that pathway in the DPM methodology.

The remedial technology to be considered in this research is a pump and treat system consisting of an air stripper and liquid carbon adsorption with off-gas carbon adsorption. The EPA's RAGS identifies fugitive emissions of volatile organic compounds, discharge to surface water of effluent treated water, and disposal of backwash and spent carbon as potential significant releases associated with the remedial technologies (USEPA, 1991: 40). Each of the six sample IRP sites were rescored by the DPM using the research established contamination characteristics and the waste containment effectiveness factors (WCEF) that represented the remedial conditions as accurate as possible. As previously stated, the WCEF is a value from 0.1 to 1.0 with a 0.1 signifying optimum containment and a 1.0 signifying little or no containment. The WCEFs selected for the pump and treat conditions were:

> Surface Water (Spill) - Contaminated material has apparently been removed completely; area is recontoured (0.1).
>
> Groundwater (Spill) - Contaminated area is covered with impervious material that is expected to prevent further infiltration and leaching (0.5).
>
> Air/Soil Volatiles (Spill) - Contaminated area is completely covered by a permanent structure such as a paved surface or building (0.2) (ODASD(E), 1992: 29,43,58).

A WCEF value of 0.1 was selected for the surface water pathway due to the minuscule chance of discharge to occur. Additionally, a WCEF value of 0.2 was chosen to represent the insignificant occurrence of fugitive emissions from an off-gas collection system. The WCEF value of 0.5 was selected for the groundwater pathway because it represented the containment of the groundwater plume from further movement. Further definitions of the WCEFs for the pathways can be found in Appendix C.

In order to demonstrate that the DPM can be used to measure risk of a remedial action, the risk scores should be dependent on the contamination characteristics - waste quantity, waste concentration, and waste containment. It would be expected that for higher original DPM risk scores there will be greater potential to decrease the risk through remedial action. A statistical analysis of the relationships between the contamination site characteristics and the data generated by rescoring the six sample sites is discussed in Chapter VI.

This effort is to determine if the relative risk of a remedial action can be measured using the DPM. It is not the focus of this research to evaluate the methods used by the DPM to calculate relative risk at contaminated sites or to validate the results of the model.

VI. ANALYSIS AND EVALUATION OF RESULTS

In order to demonstrate that the DPM can be used to measure relative risk of a remedial action, the risk scores should reflect the waste contamination conditions of the site - quantity, concentration, and containment. Each site was rescored by varying the input parameters to determine relationship between contamination conditions and individual sites. It would be expected that for higher site DPM risk scores there will be greater potential to decrease the risk through remedial action.

General Observations. Table 1 provides the breakout of the six pathway-receptor subscores for the sample sites. The pathway-hazard segments of the DPM score are significantly different depending on whether there has been a detected release (measured) or a non-detected release (potential) of a contaminant(s) into the respective pathway. For purposes of this research, detected releases of BTEX were observed in the groundwater and air/soil pathways, while the potential for BTEX contamination was calculated for the surface water pathway.

By observing the pathway-receptor scores of the sample sites calculated in Table 1, it is observed that the greatest variation in scores is the groundwater human health and ecological subscores. Considering that the pathways score and contaminant hazard score are constant for all six sites (due to the detected release of BTEX in groundwater), the considerable spread in the receptors score between the sites parallels the overall groundwater human health and ecological subscores for each site. The same statement can be interpreted for both surface water and air/soil human health and ecological subscores when considering the minimal variations observed in the pathways scores between the sites.

Finally, it was observed that the ecological pathway-receptor subscores had little influence on the final scores for each site. This was no surprise considering that the surface water-human health, groundwater-human health, and air/soil-human health

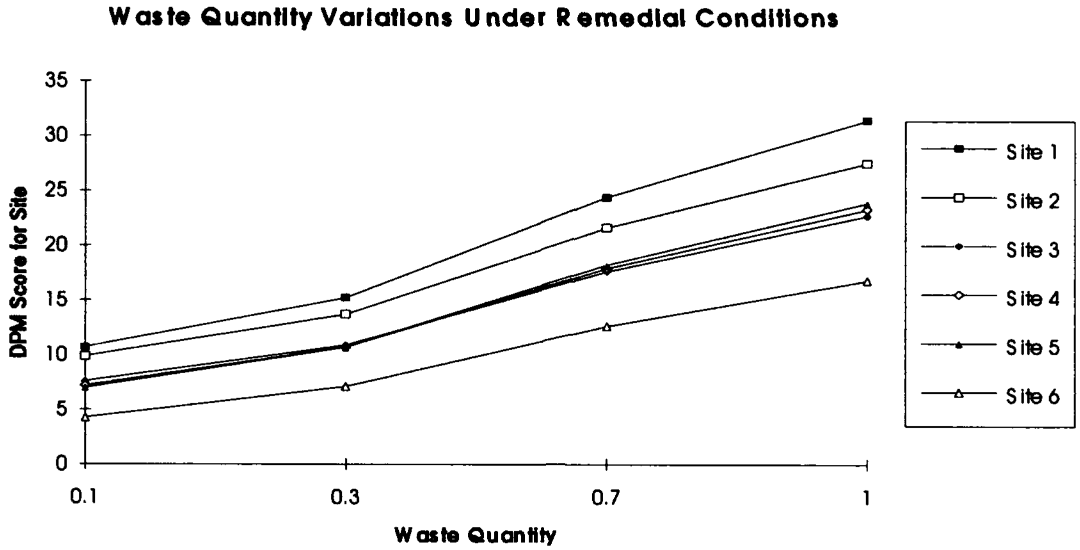
Table 1
DPM Site Scores for Remedial Action Conditions.

		Pathways		Contaminant		Receptors		Overall
		Score	X	Haz Score	X	Score	/10,000 =	Score
Surface Water/Human Health								
	Site 1	4.6		56		55.6		1.432256
	Site 2	8.2		56		37		1.69904
	Site 3	4.6		56		40.7		1.048432
	Site 4	8.7		56		48.1		2.343432
	Site 5	1.5		56		22.2		0.18648
	Site 6	3.8		56		70.4		1.498112
Surface Water/Ecological								
	Site 1	4.6		50		100		2.3
	Site 2	8.2		50		100		4.1
	Site 3	4.6		50		55.6		1.2788
	Site 4	8.7		50		100		4.35
	Site 5	1.5		50		100		0.75
	Site 6	3.8		50		27.8		0.5282
Groundwater/Human Health								
	Site 1	40		67		84.4		22.6192
	Site 2	40		67		83.8		22.4584
	Site 3	40		67		58.3		15.6244
	Site 4	40		67		51		13.668
	Site 5	40		67		41.7		11.1756
	Site 6	40		67		12.5		3.35
Groundwater/Ecological								
	Site 1	40		33		100		13.2
	Site 2	40		33		100		13.2
	Site 3	40		33		71.4		9.4248
	Site 4	40		33		57.1		7.5372
	Site 5	40		33		71.4		9.4248
	Site 6	40		33		28.6		3.7752
Air/Soil Volatiles/Human Health								
	Site 1	19.2		100		87.2		16.7424
	Site 2	19.2		100		61.5		11.808
	Site 3	22.5		100		56.4		12.69
	Site 4	20		100		71.8		14.36
	Site 5	20		100		82.1		16.42
	Site 6	20.8		100		61.5		12.792
Air/Soil Volatiles/Ecological								
	Site 1	19.2		0		100		0
	Site 2	19.2		0		33.3		0
	Site 3	22.5		0		22.2		0
	Site 4	20		0		33.3		0
	Site 5	20		0		33.3		0
	Site 6	20.8		0		0		0
		Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	
Final Score:		15.2	13.7	10.9	10.7	10.7	7.1	

subscores are weighted five times more than their respective ecological receptor subscores which reflect the national environmental regulatory policy regarding the relative importance of human health versus ecological risks. As a demonstration, the final remedial risk score for Site 1 was only reduced from 15.19 to 14.86 when the ecological receptor subscores were not taken into consideration.

Analysis of Contamination Characteristics. To determine if there is any relationship between a site remedial action DPM score and the waste quantity, waste concentration, and waste containment parameters of that site, a regression analysis was performed. It was generally observed that as the relative risk of a site under remedial conditions increased, the potential to decrease the risk of a site also increased. This was determined by statistical evaluation of the relationship between the site remedial action DPM scores and the three parameters of the contamination site.

Waste Quantity. There is a non deterministic linear relationship that can be described by the equation $Y = A(X) + B$. The independent variable (X) is the waste quantity (WQ) value for a spill and the dependent variable is the DPM score for the site. A plot and regression analysis of the data for all six sample sites is shown in Figure 6. Site 1 had the largest difference in scores, from 10.7 to 31.4, and Site 6 had the smallest difference in scores, from 4.3 to 16.8. The plot of the waste quantity versus the site scores shows that sites with a larger relative risk than other sites under similar waste contamination characteristics will generally increase at a greater rate with the increase in waste quantity factor. However, the case is not true for Site 3, Site 4, and Site 5. At a WQ of 0.1, the order of risk is Site 3 with a score of 7.6, Site 4 with a score of 7.2, and Site 5 with a score of 7.0. However, at the WQ of 1.0, the order of risk is reversed with Site 5 having the highest score (23.9) and Site 3 having the lowest score (22.7).



Site 1: $Y = 23.01(X) + 8.35, \sigma = 8.01$
Site 2: $Y = 19.60(X) + 7.89, \sigma = 6.84$
Site 3: $Y = 16.78(X) + 5.89, \sigma = 5.86$
Site 4: $Y = 17.91(X) + 5.37, \sigma = 6.25$
Site 5: $Y = 18.78(X) + 5.09, \sigma = 6.56$
Site 6: $Y = 13.87(X) + 2.92, \sigma = 4.84$

Correlation Coefficient (all sites) $\cong 1$

Figure 6. DPM Rescore Data for All Sites Versus Waste Quantity.

Reasoning behind this is indicated by the slope and standard deviation associated with the equations of the three sites. Site 5 has the largest slope and standard deviation with Site 4 and Site 3 following in order:

	Slope	Standard Deviation
Site 5	18.78	6.56
Site 4	17.91	6.25
Site 3	16.78	5.86.

The slope of the equation indicates the rate at which the DPM score will increase with the increase in the WQ. The standard deviation indicates the distribution of the data around the equation of the line. A larger standard deviation indicates a greater variance occurring among the environmental site parameters.

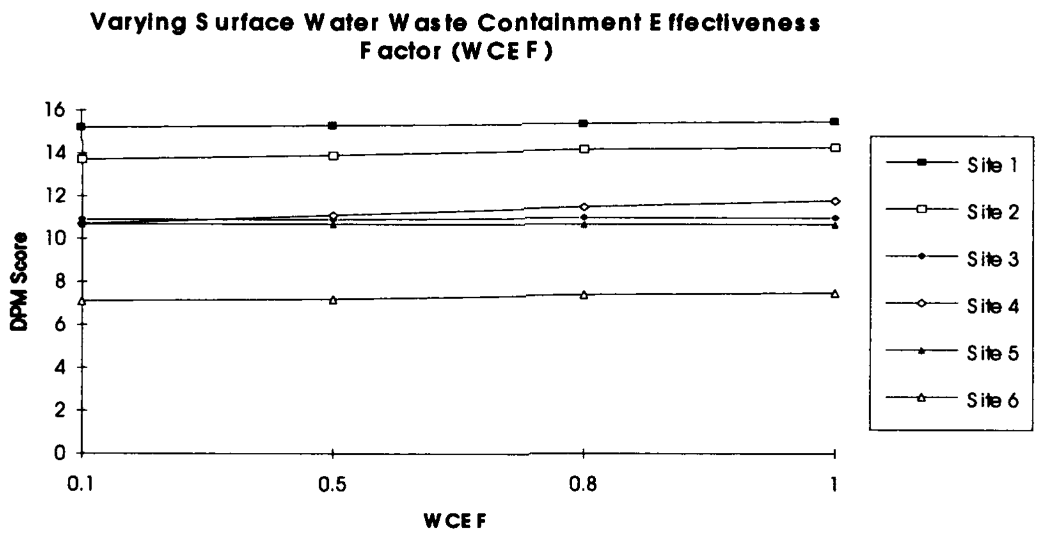
A further regression analysis was performed to determine the reasoning behind Site 5's tendency to increase in risk with WQ at a greater degree than Site 3 and Site 4. The relationship between the pathway's human health subscores (HHS) and the WQ was plotted and certain characteristics were noted:

	Surface Water Human Health	Groundwater Human Health	Air/Soil Human Health
Site 1	Y=3.59X+0.34	Y=28.3X+14.2	Y=33.45X+6.66
Site 2	Y=4.23X+0.45	Y=27.9X+14.0	Y=23.55X+4.74
Site 3	Y=2.64X+0.27	Y=19.6X+9.7	Y=25.42X+5.06
Site 4	Y=5.87X+0.62	Y=17.0X+8.6	Y=28.73X+5.74
Site 5	Y=0.45X+0.06	Y=13.9X+7.0	Y=32.87X+10.52
Site 6	Y=3.78X+0.39	Y=04.2X+2.1	Y=25.68X+5.12.

It was observed that the air/soil volatile HHS typically increased at a greater rate than the other two pathway HHSs. The exception was Site 2, installation located in Alaska, which may be due to the relative low soil temperature found in the Arctic regions. It was further observed that the air/soil volatile HHS made a considerable impact on the DPM score for Site 5 and contributed to the sites ability to surpass the risk associated with similar remedial conditions at Site 3 and Site 4. Hot, dry, windy conditions in the Southwest may explain the reason behind Site 5's greater increase in relative risk of the remedial action as the WQ increased. In addition, the relative low site score for Site 6 under remedial conditions can be attributed to the low risk associated with the groundwater pathway for that geological area. The human health subscore plots for each pathway are located in Appendix D on pages 85 to 87 for further review.

Waste Containment. A plot and regression analysis was performed for the waste containment effectiveness factor (WCEF) versus the sites DPM score. Regression analysis was performed separately for the surface water pathway WCEF, groundwater pathway WCEF, and the air/soil WCEF. As a reminder, a WCEF of 0.1 signifies optimum containment and a 1.0 signifies little or no effective containment. WCEF values between 0.1 and 1.0 represent varying degrees of containment efforts less than optimal, but greater than none. WCEF descriptives are located in Appendix C.

Figure 7 illustrates the relationship of the DPM sample site scores versus the containment efforts for the surface water pathway. Varying the surface water pathway WCEF had little to no effect on the sites' DPM scores. Site 4 had the largest range in risk, from 10.7 to 11.8, and Site 5 maintained a relative risk score of 10.7 for all values of containment. This indicates independence between the WCEF and final site remedial risk score for the case of a pathway where no contaminants are detected (referred to as a potential pathway). The lack of change in a final DPM site score further demonstrates the weight a pathway with a detected release has on the final score when compared to those

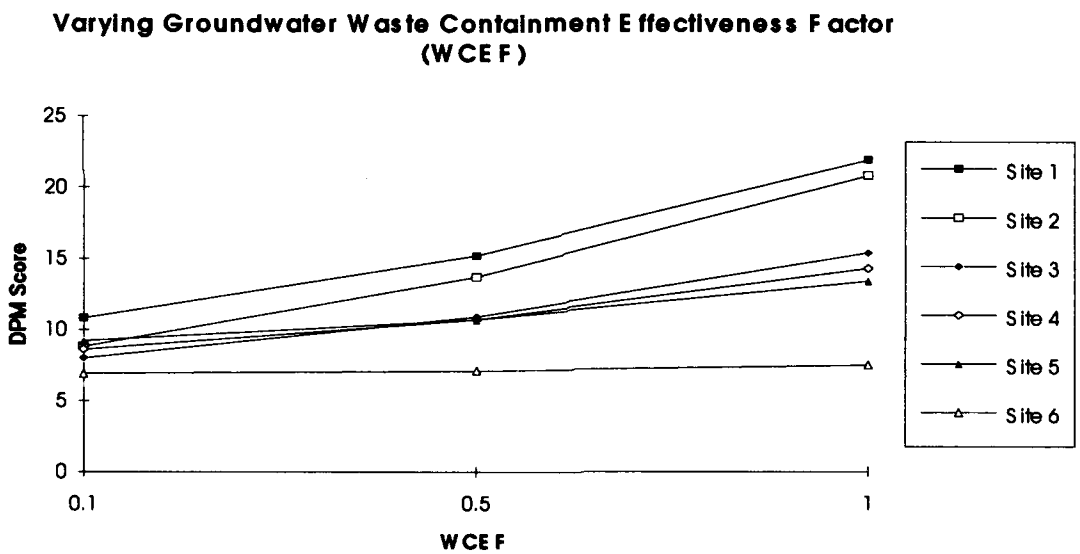


Site 1: Y = 0.33(X) + 15.15, σ = 0.112, r = 0.9891
Site 2: Y = 0.70(X) + 13.60, σ = 0.239, r = 0.9892
Site 3: Y = 0.13(X) + 10.87, σ = 0.050, r = 0.8847
Site 4: Y = 1.22(X) + 10.55, σ = 0.415, r = 0.9958
Site 5: Y = 0.00(X) + 10.70, σ = 0.000, r = 0.0000
Site 6: Y = 0.46(X) + 07.03, σ = 0.158, r = 0.9791

Figure 7. DPM Site Rescores Versus Surface Water Pathway WCEF.

pathways without detected releases. This would indicate that a RPM needs only to consider the reduction in risk of pathways with the detected releases.

Figure 8 illustrates the relationship of the DPM sample site scores versus the containment efforts for the groundwater pathway. It was observed that groundwater human health receptor variables had a significant influence on the effect groundwater containment had on the site scores. All sites, except Site 6, had high scores for the "groundwater travel time to supply wells" variable. Site 1 and Site 2 can further attribute their higher risk scores to the "population at risk from groundwater contamination" variable and the "groundwater use of the uppermost aquifer" variable. Of the three midrange risk sites, Site 3 superseded Site 4 and Site 5 in risk as the containment



Site 1: $Y = 12.38(X) + 9.37, \sigma = 4.56$
Site 2: $Y = 13.37(X) + 7.30, \sigma = 4.93$
Site 3: $Y = 08.25(X) + 7.03, \sigma = 3.04$
Site 4: $Y = 06.37(X) + 7.80, \sigma = 2.35$
Site 5: $Y = 04.70(X) + 8.60, \sigma = 1.74$
Site 6: $Y = 00.67(X) + 6.81, \sigma = 1.25$

Correlation Coefficient (all sites) $\cong 1$

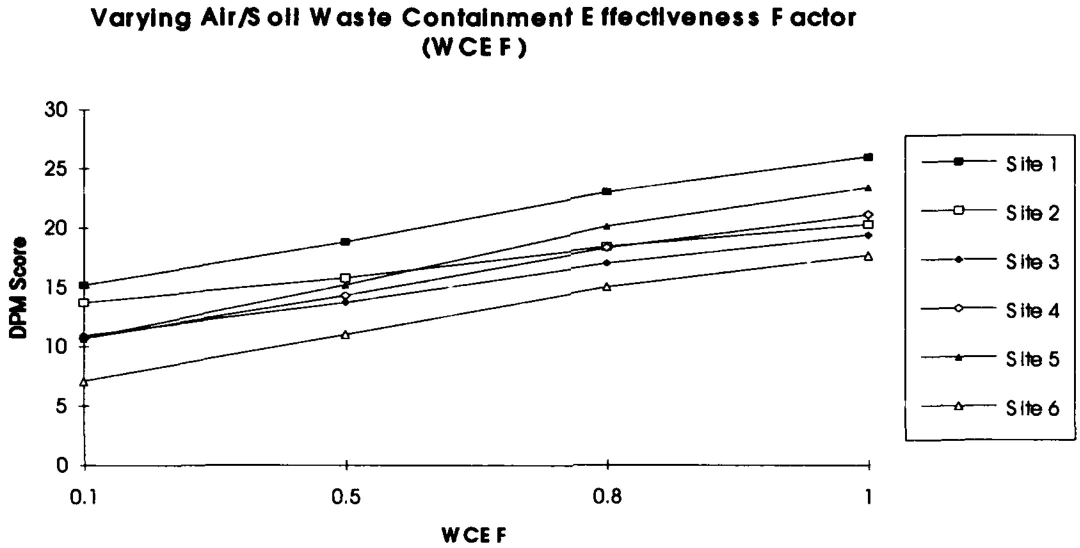
Figure 8. DPM Site Rescores Versus Groundwater Pathway WCEF

effectiveness decreased due to a larger "population at risk from groundwater contamination" score and a high "groundwater travel time to surface water" score. Site 6 had little to no increase in the risk of the remedial action as containment effectiveness decreased for the groundwater pathway.

In all cases of this research, a WCEF of 0.5 was used. The WCEF for groundwater is limited to interpretation. The three possible containment factors are 1.0 for no effective containment efforts (do nothing), 0.5 for containing the further progress of contamination movement, and 0.1 for the complete removal of contamination. It is reasonable to assume that a WCEF of 0.5 will be used for all relative risk evaluations of groundwater remediation.

The relationship of the DPM sample site scores versus the containment efforts for the last pathway, air/soil volatiles, is illustrated in Figure 9. It was observed that the containment effectiveness of the air/soil volatiles pathway had the relative same effect for the majority of the sites. The two exceptions were Site 2 and Site 5; however, these exceptions were not unexpected. Similar conditions exist for the relative risk of the two sites as was identified in the waste quantity analysis: Site 2 is located near the Arctic where average soil temperatures are very low; Site 5 is located in a dry, hot desert environment where the average soil temperature is much higher than temperate regions. Volatilization of compounds into the air is a function of soil temperature, therefore, compounds will more readily volatilize in soils at higher temperatures.

Waste Concentration. The purpose of this research was to evaluate the use of the DPM for calculating the relative risk of the remediation of Air Force sites with a risk scenario of groundwater contaminated with benzene, toluene, ethyl benzene, and xylene - contaminants present in petroleum products. Up to this point of the research analysis, the DPM scores for the sample sites have been calculated using the research established concentrations for the groundwater and air/soil pathways:



Site 1: Y = 12.0(X) + 13.55, σ = 4.10
Site 2: Y = 07.3(X) + 12.65, σ = 2.51
Site 3: Y = 09.4(X) + 09.59, σ = 3.23
Site 4: Y = 11.6(X) + 09.16, σ = 3.94
Site 5: Y = 14.2(X) + 08.86, σ = 4.82
Site 6: Y = 11.8(X) + 05.62, σ = 4.02

Correlation Coefficient (all sites) ≅ 1

Figure 9. DPM Site Rescores Versus Air/Soil Volatiles Pathway WCEF

Concentration	Groundwater Concentration (ug/l)	Air/Soil Concentration (mg/kg)
Benzene	77	0.86
Toluene	54	0.007
Ethyl Benzene	82	1.6
Toluene	150	2.7.

Of the four contaminant compounds, benzene is the only contaminant that exceeds the Clean Water Act's maximum contaminant level (MCL) for safe drinking water - 5 ug/l (Fetters, 1988: 376).

The presence of carcinogenic causing contaminants plays a significant role in determining the relative risk of a site. Of the BTEX contaminants, benzene is the only carcinogenic compound. The impact that benzene has on a site's DPM score was investigated by varying the presence of benzene at Site 5. The original score for Site 5 with a WQ of 1.0 and benzene concentrations left untouched in the groundwater and soil was 23.9. Varying the presence of benzene provided the following results:

Site Condition	DPM Site Score
No air/soil benzene	13.7
No groundwater benzene	20.8 (groundwater subscore = 0)
No air/soil, groundwater benzene	6.9
No air/soil, groundwater benzene at mcl	10.7.

The risk associated with the exposure to volatile air emissions of benzene is considerably high at Site 5. As it was for Site 5, eliminating the presence of benzene in the groundwater pathway zeroed that subscore for the remaining sample sites. It is easily observed that benzene, a carcinogenic compound, is the contaminant of concern for sites contaminated with BTEX additives.

Plot and regression analyses were performed for the benzene concentration versus DPM site score for both the groundwater and air/soil pathways. To observe the relationship of the site score and the benzene concentration, DPM scores were plotted for the four waste quantity factors of Site 1. Figure 10 illustrates the relationships for the groundwater pathway and air/soil pathway from the calculated scores presented in Table 2.. As benzene concentrations increase, variances in a site's score is much more

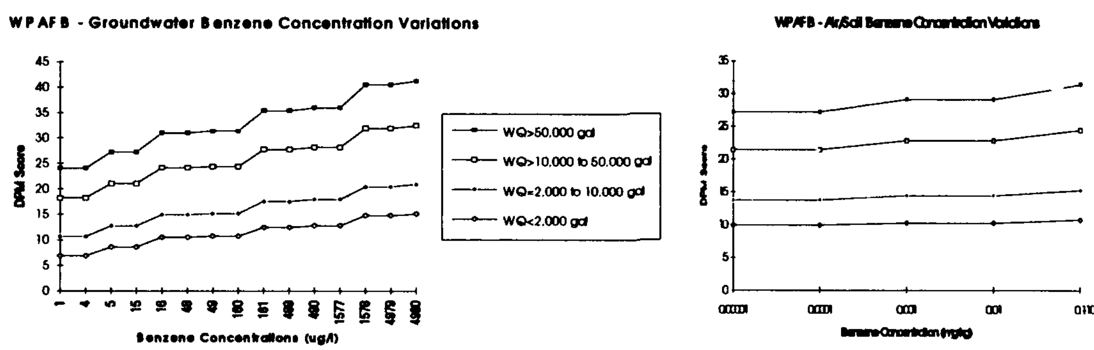


Figure 10. Site 1 Rescore Versus Benzene Concentration Variations.

Table 2
Site 1 Rescore Data for Groundwater and Air/Soil Benzene Concentration Variations.

Groundwater Concentration (ug/l)				
	WQ = 1.0	WQ = 0.7	WQ = 0.3	WQ = 0.1
1 - 4	24	18.2	10.6	6.9
5 - 15	27.2	21	12.7	8.6
16 -48	31	24.1	14.9	10.5
49 - 160	31.4	24.4	15.2	10.7
161 - 489	35.4	27.7	17.5	12.5
490 - 1577	36	28.2	17.9	12.8
1578 - 4979	40.6	31.9	20.4	14.8
4980 - 15000	41.3	32.5	20.9	15.1
Air/ Soil Concentration (mg/kg)				
	WQ = 1.0	WQ = 0.7	WQ = 0.3	WQ = 0.1
0.00001- 0.0001	27.2	21.4	13.7	9.9
0.0001- 0.01	29.1	22.8	14.4	10.2
0.1 - 100,000	31.4	24.4	15.2	10.7

evident in groundwater than the air/soil medium. However, for both cases, the mere presence of benzene made a significant impact on a site's score.

To better understand the impact benzene concentration has on a site's DPM score, plots were made of the site score versus the WQ for four conditions: (1) groundwater benzene concentration of 1 ug/l, (2) groundwater benzene concentration of 5 ug/l (MCL under the CWA), (3) groundwater benzene concentration of 77 ug/l (the baseline research concentration), and (4) groundwater benzene concentration greater than 4980 ug/l. The risk scores for each site are located in Table 3. Pages 91 to 96 in Appendix D contain the plots for all six sample sites. At the lower end of the sites scores, waste quantity of 0.1 and benzene concentration at 1 ug/l, the range of scores was from

Table 3
Sample Site Rescores for Variations in Groundwater Benzene Concentrations.

	Waste Quantity = 1.0					Waste Quantity = 0.7			
Base	4980ug/l	tc R.A. basel	MCL - 5ug	1ug/l	Base	4980ug/l	tc R.A. basel	MCL - 5ug	1ug/l
Site 1	41.3	31.4	27.2	24	Site 1	32.5	24.4	21	18.2
Site 2	40.4	27.5	22.5	18.8	Site 2	32.1	21.6	17.5	14.4
Site 3	29.4	22.7	19.9	17.9	Site 3	23.1	17.6	15.2	13.6
Site 4	28.3	23.3	21.3	19.9	Site 4	22.1	17.9	16.2	15
Site 5	27.8	23.9	22.4	21.5	Site 5	21.5	18.2	16.9	16.2
Site 6	17.4	16.8	16.6	16.5	Site 6	13.2	12.6	12.4	12.3
	Waste Quantity = 0.3					Waste Quantity = 0.1			
Base	4980ug/l	tc R.A. basel	MCL - 5ug	1ug/l	Base	4980ug/l	tc R.A. basel	MCL - 5ug	1ug/l
Site 1	20.9	15.2	12.7	10.6	Site 1	15.1	10.7	8.6	6.9
Site 2	19.7	13.7	10.8	8.6	Site 2	14.5	9.9	7.6	5.8
Site 3	14.7	10.9	9.1	7.9	Site 3	10.6	7.6	6.1	5.1
Site 4	13.7	10.7	9.4	8.5	Site 4	9.7	7.2	6.1	5.3
Site 5	13.1	10.7	9.7	9.1	Site 5	9	7	6.2	5.6
Site 6	7.5	7.1	6.9	6.9	Site 6	4.7	4.3	4.2	4.1

4.1 to 6.9. At the upper end of the site scores, waste quantity of 1.0 and benzene concentrations greater than 4979 ug/l, the range of scores was from 17.4 to 41.3. It was evident that as the WCEF increased (i.e., the containment effectiveness decreased), the spread of scores within a site increased at a greater pace for the various degrees of benzene concentrations.

Plots were also made for each sample site to determine the impact benzene concentrations in the air/soil medium had on a site's score. The score variations between sites and within sites was much smaller than what was observed for benzene concentrations in groundwater. In fact, the contamination concentration scenario established for this research was at the high end of the air/soil medium impact on the site score. The relative scores of the sample sites could only decrease; and, as Table 4 illustrates, the site scores would only decrease by a small amount. For all sample sites, the difference between the high and low concentration scores was approximately one as the waste quantity approached zero. Plots of the six sample sites are available for review on pages 97 to 102 in Appendix D.

Table 4
Sample Site Rescores for Variations in Air/Soil Volatile Benzene Concentrations.

Waste	Quantity = 1.0		Waste	Quantity = 0.7	
Base	High Conc (mg/kg)	Low Conc. (mg/kg)	Base	High Conc.	Low Conc.
Site 1	31.4	27.2	Site 1	24.4	21.4
Site 2	27.5	25.2	Site 2	21.6	19.9
Site 3	22.7	19.4	Site 3	17.6	15.2
Site 4	23.3	19	Site 4	17.9	14.8
Site 5	23.9	18.3	Site 5	18.2	14.1
Site 6	16.8	11.7	Site 6	12.6	8.8
Waste	Quantity = 0.3		Waste	Quantity = 0.1	
Base	High Conc.	Low Conc.	Base	High Conc.	Low Conc.
Site 1	15.2	13.7	Site 1	10.7	9.9
Site 2	13.7	12.9	Site 2	9.9	9.5
Site 3	10.9	9.7	Site 3	7.6	7
Site 4	10.7	9.1	Site 4	7.2	6.4
Site 5	10.7	8.6	Site 5	7	5.9
Site 6	7.1	5	Site 6	4.3	3.1

VII. CONCLUSION

Overview

Selection of the appropriate remedial action for a waste contamination site has typically been driven by cost and/or technical feasibility (Edmisten-Watkin, 1991: 293). In an increasing number of cases, the significance in considering potential human health and ecological risks in the selection of remedial alternatives has been observed when the remediation of a waste contamination site has created public health concerns distinctly different than the risks associated with the baseline conditions. Currently, the Air Force has no standard to assist RPMs in the evaluation and selection of a remedial alternative based on risk associated with the remediation action.

The Installation Restoration Program was created by the Air Force to address the problems of contaminated sites that pose a threat to public health, welfare, and the environment. An important component of CERCLA was the use of risk assessment. The Air Force developed the DPM to assist in establishing priorities for funding remedial actions based on the relative risk at IRP sites. The DPM provides a numerical score representing the relative potential risk based on the environmental conditions at a site.

The purpose of this study was to evaluate the applicability of the DPM to calculate the relative risk that would be associated with the remediation of a contaminated site. Furthermore, once a remedial alternative was selected, the relative risk of the remedial action was compared to the reduction in relative risk of the baseline site. If the relative risk of the remedial action was less than the reduction in risk of the baseline site, the remedial alternative was classified as suitable for remedial actions. The intent of this research was to provide a metric for Air Force RPMs to apply in the selection of remedial alternatives.

Objective I: Compare Relative Risk Between Remedial Alternatives

An Air Force environmental manager interviewed for this research was quick to point out that using a subjective relative risk model for purposes of determining risk-based funding created an environment where variables could be manipulated for purposes of increasing the relative risk score of the site (Clendenin, May 1994). One such variable was the waste containment effectiveness factor (WCEF). The WCEF leaves very little intermediate interpretation to a RPM. Furthermore, the limits of the WCEF make it impossible to distinguish between remedial alternatives under consideration. The only distinction that is possible between remedial technologies is the potential significant releases identified in Appendix A - Remediation Technologies and Some Potential Significant Releases. The DPM fails to consider the probabilities of failure, potential release quantities, and disposal of residual by-products that are associated with an individual remediation technology.

Objective II: Compare Reduction in Relative Risk of Site Versus Relative Risk of Selected Remedial Alternative

Figure 11 illustrates remedial action DPM scores for each sample site versus the change in baseline risk of each site from remedial efforts. For each sample site, the relative risk of the remedial action was less than the change in baseline risk from the remedial effort. Unfortunately, this will be the case for all sites using the DPM. The driving factor behind a site's DPM score is the WCEF for each pathway. The mere fact of turning on the pump in a pump and treat situation doubles the waste containment effectiveness of the groundwater pathway and reduces the pathway human health score 50%. The only way the relative risk of a remedial action will be greater than the relative risk of the reduction in baseline site risk is if the WCEF is lessened from remedial efforts.However, this will only be the case for pathways with detected releases. Referring back to page 37 and Figure 7, it was demonstrated that for a pathway where no

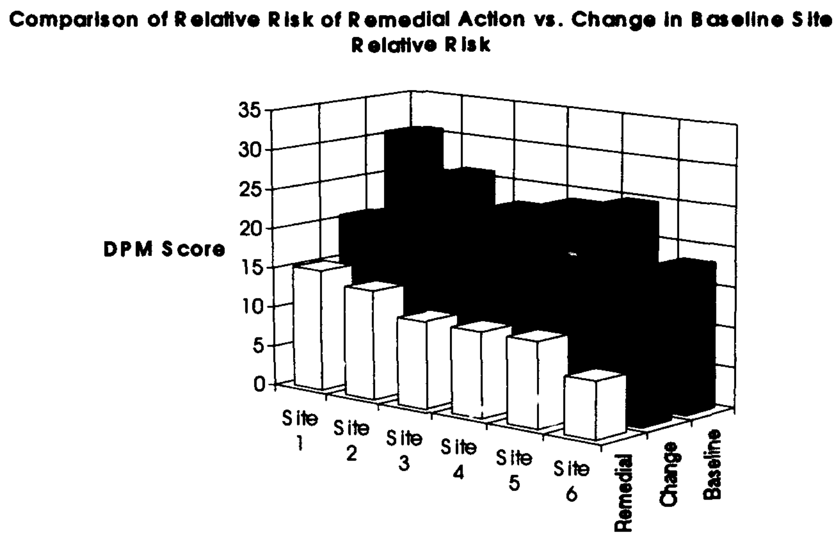


Figure 11. Comparisons Between Sample Sites' Remedial Action Scores vs. Reduction in Baseline Risk

contaminants were detected (referred to as a potential pathway) varying the WCEF had little to no effect on the final DPM score.

Recommendations

There will most likely continue to be an increasing level of interest and oversight of environmental cleanup programs such as the IRP for the next decade. Today's cleanup efforts are influenced by public concern over health risk and requirements to quickly transition closure bases for public use. In addition, environmental funding is becoming increasingly tighter with Congress expecting to see more cleanup results than risk studies (Walsch, May 1994). It is important that the Air Force be able to show continuous progress toward restoring the environment and eliminating the threat posed by the worst sites. To justify and properly manage resources for the IRP in the future, the Air Force needs to employ risk based methods to assess progress.

One area that should be investigated is the performance of absolute risk comparisons using guidelines established by The Agency for Toxic Substances and Disease Registry (ASTDR). Using the quantitative approach, the magnitude of risk and risk reduction will be established for remedial efforts. Furthermore, it will be possible to distinguish among efficiencies of remedial alternatives. Finally, quantitative risk assessments take into consideration the long term risk factors associated with remedial alternatives and the time factor.

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LIST OF ACRONYMS:

ADI	Average Daily Intake
BTEX	Benzene, Toluene, Ethyl Benzene, Xylene
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DoD	Department of Defense
DPM	Defense Priority Model
EPA	U.S. Environmental Protection Agency
FS	Feasibility Study
HARM	Hazard Assessment Risk Model
HRS	Hazard Ranking System
IRP	Installation Restoration Program
MCL	Maximum Contaminant Level
NFA	No Further Action
NPL	National Priority List
PA	Preliminary Assessment
PRGS	Preliminary Remediation Goals
RAGS	Risk Assessment Guidance for Superfund
RD/RA	Remedial Design/Remedial Action
RI	Remedial Investigation
ROD	Record of Decision
RPM	Remedial Project Manager
SARA	Superfund Amendments and Reauthorization Act
SI	Site Investigation
VOC	Volatile Organic Compound
WCEF	Waste Containment Effectiveness Factor
WQ	Waste Quantity

Appendix A: Remediation Technologies and Some Potential Significant Releases
(USEPA, 1991: 37-41)

REMEDIATION TECHNOLOGIES AND SOME POTENTIALLY SIGNIFICANT RELEASES

Technologies	Air	Water[a]	Other[b]
SOIL AND SLUDGE TECHNOLOGIES			
Soil Handling			
Soil Excavation, Transport, Dumping, Screening and Grading	• Fugitive emissions of particulates and volatiles	• Runoff or leaching of contaminants to surface or ground water	• Seepage or runoff to nearby soil
Thermal Destruction			
Incineration: Rotary Kiln, Fluidized Bed, Circulating Bed, and Infrared	• Fugitive and stack emissions of metal fumes; particulates, including metals and salts; and products of incomplete combustion, including organic compounds, acid gases, CO, NO_x, and SO_x	• Discharge of scrubber liquor and blowdown	• Disposal of ash and other solid residues
Pyrolysis	• Fugitive and stack emissions of metal fumes; particulates, including metals and salts; and products of incomplete combustion, including organic compounds, acid gases, CO, NO_x, and SO_x	• Discharge of scrubber liquor and blowdown	• Disposal of ash and other solid residues
Wet Air Oxidation	• Fugitive emissions of volatile organic compounds	• Discharge of metals and unoxidized organics	• Disposal of sludge residues
Aqueous Thermal Decomposition	• Fugitive emissions of volatile organic compounds	• Discharge of metals and unoxidized organics	• Disposal of sludge residues

(Continued)

REMEDIATION TECHNOLOGIES AND SOME POTENTIALLY SIGNIFICANT RELEASES

Technologies	Air	Water[a]	Other[b]
Dechlorination			
Glycolate Dechlorination	• Fugitive emissions of volatile organic compounds	• Discharge of spent solvents and degraded contaminants to surface water, or leaching to ground water	
Biological Treatment			
Composting	• Fugitive emissions of particulates and volatile organics	• Leaching of metals and/or organics	
In-situ Biodegradation	• Fugitive emissions of volatile organics	• Leaching of metals and/or organics • Discharge of treated water	
Slurry-phase or Solid-phase Biodegradation	• Fugitive emissions of volatile organics	• Discharge of non-degraded byproducts in slurry liquor and treated effluent • Runoff to surface water or to ground water (with solid-phase process)	• Disposal of residual biomass which may contain hazardous metals and refractory organics
Vacuum/Vapor Extraction, Thermal Desorption			
Low Temperature Thermal Stripping	• Stack emissions of volatile organics • Fugitive emissions of volatile organics	• Discharge of scrubber blowdown • Discharge of contaminant condensate	
In-situ Vacuum/Steam Extraction	• Fugitive emissions of volatile organics	• Discharge of contaminant or water condensate	• Disposal or regeneration of spent activated carbon

(Continued)

REMEDIATION TECHNOLOGIES AND SOME POTENTIALLY SIGNIFICANT RELEASES

Technologies	Air	Water[a]	Other[b]
Chemical Extraction & Soil Washing			
In-situ Chemical Treatment	• Fugitive emissions of volatile organic compounds	• Runoff of uncontained treatment chemicals	• Possible solvent residuals in treated soil
Chemical or Solvent Extraction	• Fugitive emissions of volatile organic compounds	• Post-extraction discharge of wastewater with extracted contaminants	• Possible solvent residuals in treated soil
Soil Washing	• Fugitive emissions of volatile organic compounds	• Post-washing discharge of wastewater with extracted contaminants	• Discharge of foam with metals and organics • Deposition of sedimentation sludge residuals • Deposition of untreated, contaminated fines
In-situ Soil Flushing	• Fugitive emissions of volatile organic compounds	• Leaching of contaminated flush water, acids, bases, chelating agents, or surfactants	
Immobilization			
Capping	• Fugitive emissions of particulates and volatiles during cap construction	• Leaching of contaminants to ground water	• Lateral movement of volatile organic compounds after capping
Solidification/Stabilization	• Fugitive emissions of particulates and volatiles	• None likely	• Potential leaching to soils and ground water of contaminants from deposited material over time

(Continued)

REMEDIATION TECHNOLOGIES AND SOME POTENTIALLY SIGNIFICANT RELEASES

Technologies	Air	Water[a]	Other[b]
In-situ Vitrification	• Surface fugitive emissions of volatile organics and volatile metals during the process	• Discharge of scrubber solution • Possible contamination of ground water under the treatment area	• Potential lateral migration of vaporized or leached contaminants into the soil that surrounds the vitrified monolith
GROUNDWATER AND SURFACE WATER TECHNOLOGIES			
Non-Treatment Actions			
Natural Attenuation	• Emissions of volatile organic compounds	• Aquifer discharge to surface water • Continued aquifer transport of contaminants	
Pump without Treatment	• Emissions of volatile organic compounds	• Discharge of untreated water to surface water or Publicly Owned Treatment Works (POTW) • Seepage of untreated water	• Disposal of sludge residuals from POTW
Air Stripping	• Stack and fugitive emissions of volatile organics	• Discharge to surface water of effluent treated water with residual metals, particulates, or nonvolatile organics	• Disposal of backwash or cleaning residues
Filtration/Settling	• Fugitive emissions of volatile organic compounds from settling basin	• Discharge of effluent water containing dissolved solids or unremoved particles	• Disposal of filter cake or sludge containing organics, metals, or other inorganics
Granular Activated Carbon Adsorption	• None likely	• Discharge of effluent with non-adsorbable, low molecular weight compounds	• Disposal and/or regeneration of spent carbon

(Continued)

REMEDIATION TECHNOLOGIES AND SOME POTENTIALLY SIGNIFICANT RELEASES

Technologies	Air	Water[a]	Other[b]
Ion Exchange	• None likely	• Discharge of backwash water	• Disposal and/or regeneration of spent resins
Chemical Treatment	• Fugitive emissions of volatile organic compounds from treatment tanks	• Discharge of effluent with treatment residues	• Disposal of treatment sludges
Biological Treatment	• Emissions of volatile organics in aerobic treatment or due to aeration	• Discharge of effluent with unremoved solids	• Disposal of treatment sludges
Membrane Separation			
Reverse Osmosis	• None likely	• Discharge of effluent containing unfiltered organics (depends on filter membrane used)	• Discharge of concentrate stream with contaminants removed from treated water
Electrodialysis	• None likely	• Discharge of treated effluent	• Discharge of concentrate stream with contaminants removed from treated water

Notes:

[a] In general, seepage and leaching are more likely to affect ground water, but could also contaminate surface water. Runoff and discharge are releases that will most likely contaminate surface water, but could also contaminate ground water.

[b] Other releases include treatment residuals that need further treatment or proper disposal. In most cases, this column refers to sludge or solid residues that may also be hazardous.

Appendix B: DPM Algorithm
(ODASD(E), 1992: G1-G12)

SURFACE WATER PATHWAY

	Score (circle one)	Multiplier	Score Product (score × mult.)	Maximum Score	Confidence Factor (0-1)
<u>Detected Releases</u>					
1. Have contaminants been detected in surface water? If yes, assign score of 100 and proceed to item [10]. If no, assign a score of 0 and proceed to item [2].	0 100	1	___	100	___
<u>Pathway Characteristics</u>					
2. Distance to nearest surface water	0 1 2 3	4	___	12	___
3. Net precipitation	0 1 2 3	1	___	3	___
4. Surface erosion potential	0 1 2 3	4	___	12	___
5. Rainfall intensity	0 1 2 3	4	___	12	___
6. Surface hydraulic conductivity	0 1 2 3	3	___	9	___
7. Flooding potential	0 1 2 3	10	___	30	___
8. Sum of items [2] through [7]			___	78	___
9. Normalized score (item [8] × 100/78)			___		
10. Waste containment effectiveness factor			___		___
11. Waste quantity factor			___		___
12. Final pathway score for surface water (item [9] × (item [10] + item [11])/2).			___		___

GROUND WATER PATHWAY

Detected Releases	Score (circle one)	Multiplier	Score-Product (score × mult.)	Maximum Score	Confidence Factor (0-1)
13. Have contaminants been detected in ground water? If yes, assign score of 100 and proceed to item [20]. If no, assign score of 0 and proceed to item [14].	0 100	1	___	100	___
Pathway Characteristics					
14. Distance to seasonal high ground water from base of waste or contaminated zone and potential for discrete features in the unsaturated zone to "short circuit" the pathway to the water table	0 1 2 3 4 5 6	10	___	60	___
15. Hydraulic conductivity of the unsaturated zone	0 1 2 3	5	___	15	___
16. Infiltration potential	0 1 2 3	5	___	15	___
17. Geochemical properties of the vadose zone	0 1 2 3	5	___	15	___
18. Sum of items [14] through [17]			___	105	
19. Normalized score (item [18] × 100/105)			___		
20. Waste containment effectiveness factor			___		___
21. Waste quantity factor			___		___
22. Final pathway score for ground water (item [19] × (item [20] + item [21])/2)			___		___

AIR/SOIL VOLATILES PATHWAY

Detected Releases	Score (circle one)	Multiplier	Score Product (score × mult.)	Maximum Score	Confidence Factor (0-1)
23. Have volatile contaminants been detected in ambient air above background levels? If yes, assign score of 100 and proceed to item [32]. If no, assign score of 0 and proceed to item [24].	0 100	1	___	100	___
Pathway Characteristics					
24. Have volatile contaminants been detected in surface soil? If yes, assign a score of 3 and proceed to item [25]. If no, assign a score of 0 to items [24] and [34], and proceed to item [35].	0 3	12	___	36	___
25. Average summer soil temperature	0 1 2 3	2	___	6	___
26. Net precipitation	0 1 2 3	2	___	6	___
27. Wind velocity	0 1 2 3	2	___	6	___
28. Soil porosity	0 1 2 3	2	___	6	___
29. Sum of items [24] through [28]			___	60	
30. Normalized score (item [29] × 100/60)			___		
31. Adjusted pathways score. If item [23] is 100, enter 100. If item [23] is 0 and item [24] is 0, enter 0. If item [24] is not 0, enter value from item [30].			___		
32. Waste containment effectiveness factor			___		___
33. Waste quantity factor			___		___
34. Final pathway score for air/soil volatiles (item [31] × (item [32] + item [33])/2)			___		___

AIR/SOIL DUST PATHWAY

Detected Releases	Score (circle one)	Multiplier	Score Product (score × mult.)	Maximum Score	Confidence Factor (0-1)
35. Have non-volatile contaminants been detected in ambient air above background levels? If yes, assign score of 100 and proceed to item [44]. If no, assign score of 0 and proceed to item [36].	0 100	1	___	100	___
Pathway Characteristics					
36. Have non-volatile contaminants been detected in the surface soil? If yes, assign a score of 3 and proceed to item [37]. If no, assign a score of 0 to items [36] and [46], and proceed to item [47].	0 3	12	___	36	___
37. Net precipitation	0 1 2 3	2	___	6	___
38. Wind velocity	0 1 2 3	2	___	6	___
39. Days/year > 0.25 mm precipitation	0 1 2 3	2	___	6	___
40. Site activity	0 1 2 3	2	___	6	___
41. Sum of items [36] through [40]			___	60	
42. Normalized score (item [41] × 100/60)			___		
43. Adjusted pathways score. If item [35] is 100, enter 100. If item [35] is 0 and item [36] is 0, enter 0. If item [36] is not 0, enter value from item [42].			___		
44. Waste containment effectiveness factor			___		___
45. Waste quantity factor			___		___
46. Final pathway score for air/soil dust (item [43] × (item [44] + item [45])/2)			___		___

CONTAMINANT HAZARD–SURFACE WATER

If contaminants have been detected in surface water (score of 100 in item [1]), complete items [47] through [52]. If contaminants have not been detected (score of 0 in item [1]), complete items [53] through [56].

	Score (circle one)	Result		Confidence Factor (0-1)
47. Sum of Health Hazard Quotients (from column 9 of the Surface Water Hazard Worksheet for detected releases).		___		
48. Human Health Hazard Score (Table G-1).	0 1 2 3 4 5 6	___		
49. Final Health Hazard Score for surface water pathway (item [48] × 100/6).		___		___
50. Sum of Ecological Hazard Quotients (enter the larger of the sum of column 10 of the Surface Water Hazard Worksheet for detected releases).		___		
51. Ecological Hazard Score (Table G-2).	0 1 2 3 4 5 6	___		
52. Final Ecological Hazard Score for surface water pathway (item [51] × 100/6).		___		___
53. Maximum Health Hazard Score (from column 2 of the Surface Water Hazard Worksheet for non-detected releases).	0 1 2 3 4 5 6 7 8 9		Contaminant: ______	
54. Final Health Hazard Score for surface water pathway (item [53] × 100/9).		___		___
55. Maximum Ecological Hazard Score (from column 3 of the Surface Water Hazard Worksheet for non-detected releases).	0 1 2 3 4 5 6		Contaminant: ______	
56. Final Ecological Hazard Score for surface water pathway (item [55] × 100/6).		___		___

CONTAMINANT HAZARD—GROUND WATER

If contaminants have been detected in ground water (score of 100 in item [13]), complete items [57] through [62]. If contaminants have not been detected (score of 0 in item [13]), complete items [63] through [66].

	Score (circle one)	Result		Confidence Factor (0-1)
57. Sum of Health Hazard Quotients (from column 9 of Ground Water Hazard Worksheet for detected releases).		___		
58. Human Health Hazard Score (Table G-1).	0 1 2 3 4 5 6	___		
59. Final Health Hazard Score for ground water pathway (item [58] × 100/6).		___		___
60. Sum of Ecological Hazard Quotients (column 10 Ground Water Hazard Worksheet for detected releases).		___		
61. Ecological Hazard Score (Table G-2).	0 1 2 3 4 5 6	___		
62. Final Ecological Hazard Score for ground water pathway (item [61] × 100/6).		___		___
63. Maximum Health Hazard Score (from column 11 of the Ground Water Hazard Worksheet for non-detected releases).	0 1 2 3 4 5 6 7 8 9		Contaminant: ______	
64. Final Health Hazard Score for ground water pathway (item [63] × 100/9).		___		___
65. Maximum Ecological Hazard Score (from column 12 of the Ground Water Hazard Worksheet for non-detected releases).	0 1 2 3 4 5 6		Contaminant: ______	
66. Final Ecological Hazard Score for ground water pathway (item [65] × 100/6).		___		___

CONTAMINANT HAZARD–AIR/SOIL VOLATILES

If volatile contaminants have been detected in ambient air (score of 100 in item [23]), or if volatile contaminants have been detected in surface soil (score of 36 in item [24]) complete items [67] through [72]. If volatile contaminants have not been detected in air or soil, proceed to [77].

	Score (circle one)	Result	Confidence Factor (0-1)
67. Sum of Health Hazard Quotients (from column 7 of the Air/Soil Volatile Hazard Worksheet).		___	
68. Human Health Hazard Score (Table G-1).	0 1 2 3 4 5 6	___	
69. Final Health Hazard Score for air/soil volatile pathway (item [68] × 100/6).		___	___
70. Sum of Terrestrial Hazard Quotients (from column 8 of the Air/Soil Volatile Hazard Worksheet).		___	
71. Ecological Hazard Score (Table G-2).	0 1 2 3 4 5 6	___	
72. Final Ecological Hazard Score for air/soil volatile pathway (item [71] × 100/6).		___	___

CONTAMINANT HAZARD--AIR/SOIL DUST

If non-volatile contaminants have been detected in ambient air (score of 100 in item [35]), or if non-volatile contaminants have been detected in surface soil (score of 36 in item [36]) complete items [77] through [82]. If non-volatile contaminants have not been detected in air or soil, proceed to [87].

	Score (circle one)	Result	Confidence Factor (0-1)
77. Sum of Health Hazard Quotients (from column 9 of the Air/Soil Dust Hazard Worksheet).		___	
78. Human Health Hazard Score (Table G-1).	0 1 2 3 4 5 6	___	
79. Final Health Hazard Score for air/soil dust pathway (item [78] × 100/6).		___	___
80. Sum of Terrestrial Hazard Quotients (from column 10 of the Air/Soil Dust Hazard Worksheet).		___	
81. Ecological Hazard Score (Table G-2).	0 1 2 3 4 5 6	___	
82. Final Ecological Hazard Score for air/soil dust pathway (item [81] × 100/6).		___	___

HUMAN HEALTH RECEPTORS–SURFACE WATER PATHWAY

	Score (circle one)	Multiplier	Score Product (score × mult.)	Maximum Score	Confidence Factor (0-1)
87. Population that obtains drinking water from potentially affected surface water body(ies) downstream	0 1 2 3	3	___	9	___
88. Water use of nearest surface water body(ies)	0 1 2 3	3	___	9	___
89. Population within ½ mi (806 m) of the site	0 1 2 3	1	___	3	___
90. Distance to the nearest installation boundary	0 1 2 3	1	___	3	___
91. Land use and/or zoning within 2 miles (3.2 km) of the site	0 1 2 3	1	___	3	___
92. Sum of items [87] through [91]			___	27	
93. Final Human Health Receptors score for surface water pathways (item [92] × 100/27)			___		___

ECOLOGICAL RECEPTORS–SURFACE WATER PATHWAYS

	Score (circle one)	Multiplier	Score Product (score × mult.)	Maximum Score	Confidence Factor (0-1)
94. Importance/sensitivity of biota/ habitats in potentially affected surface water bodies nearest the site	0 1 2 3	5	___	15	___
95. Presence of "critical environments" within 1.5 miles (2.4 km) of the site	0 3	1	___	3	___
96. Sum of items [94] and [95]			___		
97. Final Ecological Receptors score for surface water pathways (item [96] × 100/18)			___	18	___

HUMAN HEALTH RECEPTORS–GROUND WATER PATHWAY

		Score (circle one)	Multiplier	Score Product (score × mult.)	Maximum Score	Confidence Factor (0-1)
98.	Estimated mean ground water travel time from waste location to nearest downgradient water supply well(s)	0 1 2 3	9	___	27	___
99.	Estimated mean ground water travel time from current waste location to any downgradient surface water body that supplies water for domestic use or for food chain agriculture	0 1 2 3	5	___	15	___
100.	Ground water use of the uppermost aquifer	0 1 2 3	4	___	12	___
101.	Population potentially at risk from ground water contamination	0 3 6 9 12 18 24 27 36	1	___	36	___
102.	Population within ½ mi (806 m) of the site	0 1 2 3	1	___	3	___
103.	Distance to the nearest installation boundary	0 1 2 3	1	___	3	___
104.	Sum of items [98] through [103]			___	96	
105.	Final Human Health Receptors score for ground water pathways (item [104] × 100/96)			___		___

ECOLOGICAL RECEPTORS–GROUND WATER PATHWAYS

		Score (circle one)	Multiplier	Score Product (score × mult.)	Maximum Score	Confidence Factor (0-1)
106.	Estimated mean ground water travel time from waste location to any downgradient habitat or natural areas	0 1 2 3	3	___	9	___
107.	Importance/sensitivity of downgradient biota/habitats that are confirmed or suspected ground water discharge points	0 1 2 3	3	___	9	___

HUMAN HEALTH RECEPTORS–GROUND WATER PATHWAY (concluded)

		Score (circle one)	Multiplier	Score Product (score × mult.)	Maximum Score	Confidence Factor (0-1)
108.	Presence of "critical environments" within 1.5 miles (2.4 km) of the site	0 1 3	1	___	3	___
109	Sum of items 106 through 108			___	21	
110.	Final Ecological Receptors score for ground water pathways (item [109] × 100/21)			___		___

HUMAN HEALTH RECEPTORS–AIR/SOIL VOLATILES/DUST PATHWAYS

		Score (circle one)	Multiplier	Score Product (score × mult.)	Maximum Score	Confidence Factor (0-1)
111.	Population within 4 mile radius	0 9 12 15 18 21 24 27 30	1	___	30	___
112.	Land use	0 1 2 3	2	___	6	___
113.	Distance to nearest installation boundary	0 1 2 3	1	___	3	___
114.	Sum of items [111] through [113]			___	39	
115.	Final Human Health Receptors score for air pathways (item [114] × 100/39)			___		___

ECOLOGICAL RECEPTORS–AIR/SOIL VOLATILES/DUST PATHWAYS

116.	Distance to sensitive environment	0 1 2 3	2	___	6	___
117.	Presence of "critical environments" within 1.5 mile (2.4 km) of the site	0 3	1	___	3	___
118.	Sum of items [116] and [117]			___	9	
119.	Final Ecological Receptors score for air pathways (item [118] × 100/9)			___		___

SCORING SUMMARY SHEET

		Pathways Score	Contaminant Hazard Score	Receptors Score	Overall Score
120.	Surface water/human health scores	(_____ × item [12]	_____ × item [49]/[54]	_____) /10,000 = item [93]	___
121.	Surface water/ ecological scores	(_____ × item [12]	_____ × item [52]/[56]	_____) /10,000 = item [97]	___
122.	Ground water/human health scores	(_____ × item [22]	_____ × item [59]/[64]	_____) /10,000 = item [105]	___
123.	Ground water/ ecological scores	(_____ × item [22]	_____ × item [62]/[66]	_____) /10,000 = item [110]	___
124.	Air/Soil volatiles human score	(_____ × item [34]	_____ × item [69]	_____) /10,000 = item [115]	___
125.	Air/Soil volatiles ecological scores	(_____ × item [34]	_____ × item [72]	_____) /10,000 = item [119]	___
126.	Air/Soil dust human health scores	(_____ × item [46]	_____ × item [79]	_____) /10,000 = item [115]	___
127.	Air/Soil dust ecological score	(_____ × item [46]	_____ × item [82]	_____) /10,000 = item [119]	___

OVERALL SITE SCORE

In this equation use the higher of the following pairs of values ([126] or [124]) and ([127] or [125]).

128. $[(\underbrace{\_\_\_}_{\text{item [120]}})^2 \times 5 + (\underbrace{\_\_\_}_{\text{item [121]}})^2 + (\underbrace{\_\_\_}_{\text{item [122]}})^2 \times 5 + (\underbrace{\_\_\_}_{\text{item [123]}})^2 + (\underbrace{\_\_\_}_{\text{item [124] or [126]}})^2 \times 5 + (\underbrace{\_\_\_}_{\text{item [125] or [127]}})^2]^{1/2} = \_\_\_\_\_\_$

129. Over all site score = $\dfrac{\_\_\_\_\_}{\text{item [128]}} /4.24 = \_\_\_\_\_$

Appendix C: Waste Containment Effectiveness Factors and Waste Quantity Factors

(ODASD(E), 1992: 27-33, 42-46, 57-59, 68-70)

Waste quantity factors for site types other than landfills [11, 21, 33, 45]		
Surface Impoundments	Size of Impoundment	Score
	<1 acre	0.1
	1 to 10 acres	0.3
	>10 to 20 acres	0.7
	>20 acres	1.0
Spills	Quantity of Waste	Score
	<2,000 gal	0.1
	2,000 to 10,000 gal	0.3
	>10,000 to 50,000 gal	0.7
	>50,000 gal	1.0
Fire Training Areas	Years Used	Score
	<10 years	0.1
	10 to 15 years	0.3
	>15 to 20 years	0.7
	>20 years	1.0
Waste Piles	Size of Area	Score
	<1 acre	0.1
	1-3 acres	0.3
	>3-5 acres	0.7
	>5 acres	1.0
Above Ground Tanks	Quantity of Waste	Score
	<5,000 gal	0.1
	5,000 to 10,000 gal	0.3
	>10,000 to 100,000 gal	0.7
	>100,000 gal	1.0
Underground Tanks	Quantity of Waste	Score
	<5,000 gal	0.1
	>5,000 to 50,000 gal	0.3
	>50,000 to 100,000 gal	0.7
	>100,000 gal	1.0
Enclosed Structures	Size of Structure	Score
	<2,500 ft^2	0.1
	2,500 to 10,000 ft^2	0.3
	>10,000 to 50,000 ft^2	0.7
	>50,000 ft^2	1.0
Contaminated Ground Water	Plume Size	Score
	<0.5 miles	0.1
	0.5 to 1 mile	0.3
	>1 to 2 miles	0.7
	>2 miles	1.0

Waste containment effectiveness factors for surface water [10]	
Uncapped Landfill	**Score**
• Contaminated material has apparently been removed completely; area is recontoured.	0.1
• Contaminants are present but appear to be effectively contained. • Contaminated area is covered with an impervious material not normally subject to cracking. • Covered with adequate thickness of clean soil and revegetated. • Any significant run-on to area is diverted; if area is in a floodplain, dikes/berms effectively prevent floodwater encroachment.	0.5
• Limited containment; contaminated area is covered effectively but needed run-on diversion or flood protection is absent. • Contaminants may be exposed, but the area is protected from significant run-on or flooding, and surface runoff from the area is collected and treated.	0.8
• Contaminants may be exposed. Any runoff from the site would not be collected and treated.	1.0

Waste containment effectiveness factors for surface water [10]	
Capped Landfill	**Score**
• Site surface is properly graded. • Clay cap or other cover is in sound condition. • Any potential run-on is effectively diverted away from the landfill area. • If the landfill is in a floodplain, dikes or berms effectively prevent floodwater encroachment.	0.1
• Site is covered adequately and run-on diversion or flood protection structures are present, if needed. Minor problems exist with either the cover or dike/diversion structures (e.g., dike is in poor repair or the site surface is not adequately vegetated).	0.5
• Waste is covered effectively, but needed run-on diversion or flood protection structures are absent. • Waste is covered and any needed dike/diversion structures are present, but the cover is in very poor condition [extensive rill erosion has occurred, or clay/soil cover is less than 1 ft (0.3 m) thick].	0.8
• Waste is exposed or leachate seeps have been reported.	1.0

Waste containment effectiveness factors for surface water [10]	
Liquid Containing Surface Impoundment	**Score**
• Sound dikes and adequate freeboard; if there is an effluent, it is treated and discharged in compliance with permits.	0.1
• Sound dikes, but inadequate freeboard. • No evidence of past overflows or uncontrolled discharge.	0.5
• Dikes are not leaking nor are they in apparent danger of collapse, but there is some evidence of potential unsoundness (e.g., earthen dikes are eroded). • No evidence of past overflows or uncontrolled discharge.	0.8
• Dikes are leaking or in danger of collapse. • There is evidence of past overflows or uncontrolled discharges.	1.0

Waste containment effectiveness factors for surface water [10]	
Non-liquid Containing Surface Impoundment	**Score**
• Site surface is properly graded. • Clay cap or other cover is in sound condition. • Any potential run-on is effectively diverted away from the landfill area. • If the surface impoundment is in a floodplain, dikes or berms effectively prevent floodwater encroachment.	0.1
• Site is covered adequately and run-on diversion or flood protection structures are present, if needed. Minor problems exist with either the cover or dike/diversion structures (e.g., dike is in poor repair or the site surface is not adequately vegetated).	0.5
• Waste is covered effectively, but needed run-on diversion or flood protection structures are absent. • Waste is covered and any needed dike/diversion structures are present, but the cover is in very poor condition [extensive rill erosion has occurred, or clay/soil cover is less than 1 ft (0.3 m) thick].	0.8
• Waste is exposed or leachate seeps have been reported.	1.0

Waste containment effectiveness factors for surface water [10]	
Spill	**Score**
• Contaminated material has apparently been removed completely; area is recontoured.	0.1
• Contaminants are present but appear to be effectively contained. • Contaminated area is covered with an impervious material not normally subject to cracking. • Covered with adequate thickness of clean soil and revegetated. • Any significant run-on to area is diverted; if area is in a floodplain, dikes/berms effectively prevent floodwater encroachment.	0.5
• Limited containment; contaminated area is covered effectively but needed run-on diversion or flood protection is absent. • Contaminants may be exposed, but the area is protected from significant run-on or flooding, and surface runoff from the area is collected and treated.	0.8
• Contaminants may be exposed. Any runoff from the site would not be collected and treated.	1.0

Waste containment effectiveness factors for surface water [10]	
Former Fire Training Area	**Score**
• Contaminated material has apparently been removed completely; area is recontoured.	0.1
• Contaminants are present but appear to be effectively contained. • Contaminated area is covered with an impervious material not normally subject to cracking. • Covered with adequate thickness of clean soil and revegetated. • Any significant run-on to area is diverted; if area is in a floodplain, dikes/berms effectively prevent floodwater encroachment.	0.5
• Limited containment; contaminated area is covered effectively but needed run-on diversion or flood protection is absent. • Contaminants may be exposed, but the area is protected from significant run-on or flooding, and surface runoff from the area is collected and treated.	0.8
• Contaminants may be exposed. Any runoff from the site would not be collected and treated.	1.0

Waste containment effectiveness factors for surface water [10]	
Active Fire Training Area	**Score**
• Area is surrounded by sound concrete containment structures with adequate freeboard to prevent overflows. • Area is protected from floodwater encroachment. • Effluent from the area is collected, pretreated in an oil-water separator, and sent to a wastewater treatment plant.	0.1
• Containment structures are sound but lack adequate freeboard. Effluent from the area is collected, pretreated in an oil/water separator, and sent to a wastewater treatment plant.	0.5
• Potential unsoundness in containment structures (e.g., constructed of earthen materials instead of concrete). Effluent from the area is collected pretreated in an oil/water separator, and sent to a wastewater treatment plant.	0.8
• Surface effluent from area is not controlled. • Effluents are discharged directly from oil/water separator.	1.0

Waste containment effectiveness factors for surface water [10]	
Waste Piles	**Score**
• Contaminated material has apparently been removed completely; area is recontoured.	0.1
• Contaminants are present but appear to be effectively contained. • Contaminated area is covered with an impervious material not normally subject to cracking. • Covered with adequate thickness of clean soil and revegetated. • Any significant run-on to area is diverted; if area is in a floodplain, dikes/berms effectively prevent floodwater encroachment.	0.5
• Limited containment; contaminated area is covered effectively but needed run-on diversion or flood protection is absent. • Contaminants may be exposed, but the area is protected from significant run-on or flooding, and surface runoff from the area is collected and treated.	0.8
• Contaminants may be exposed. • Any runoff from the site would not be collected and treated.	1.0

Waste containment effectiveness factors for surface water [10]	
Above Ground Tank	**Score**
• Above ground tanks and piping are in sound condition and inspected regularly. • Tank area and associated transfer facilities are surrounded by a sound surface-water diversion system. • It is bermed to prevent floodwater encroachment and to contain spills. • No evidence of past leaks or spills.	0.1
• Above ground tanks and piping are in sound condition and tank area is bermed. Berms need repair or may be inadequate to contain spillage and subsequent rainfall.	0.5
• Above ground tanks and piping in sound condition but the area is not bermed. • Tanks are sound and the area is properly bermed, but there is evidence of past leaks or spills within the bermed area.	0.8
• Above ground tanks or piping are not in sound condition (e.g., they are visibly corroded or leaking); there is evidence of past leaks or spills in areas not protected by berms.	1.0

Waste containment effectiveness factors for surface water [10]	
Underground Tank	**Score**
• Impact on surface water is not likely.	0.1

Waste containment effectiveness factors for surface water [10]	
Site within Enclosed Structures	**Score**
• Tanks, piping, containers, etc., are in sound condition and are inspected regularly. • Drainage from hazardous-material handling and storage areas is isolated from floor drain systems that connect to storm water drainage systems or sanitary sewers and is treated properly. • Any past spills or leaks are cleaned up completely.	0.1
• Tanks, piping, containers, etc., are in sound condition and are inspected regularly. • There is no evidence of past spills or leaks, but drainage from hazardous-material handling and storage areas is not effectively isolated from floor drain systems that connect to storm water drainage systems or sanitary sewers.	0.5
• Tanks, piping, containers, etc., are not in sound condition. • There is evidence of past spills or leaks, but drainage from hazardous-material handling. Storage area are isolated from the floor drain systems that connect to storm water drainage systems or sanitary sewers.	0.8
• Tanks, piping, containers, etc., are not in sound condition. • There is evidence of past spills or leaks, and drainage from hazardous-material handling. • Storage areas are <u>not</u> effectively isolated from floor drain systems that connect to storm water drainage systems or sanitary sewers.	1.0

Waste containment effectiveness factors for surface water [10]	
Site with Ground Water Contamination	**Score**
• Impact on surface water is not likely.	0.1

Waste containment effectiveness factors for ground water pathways [20]	
Uncapped Landfills	**Score**
• Contaminated materials appear to have been removed completely.	0.1
• Contaminated area is covered with impervious material that is expected to prevent further infiltration and leaching.	0.5
• No clean-up action or covering has been done.	1.0

Waste containment effectiveness factors for ground water pathways [20]	
Capped Landfills	**Score**
• Liner is essentially impermeable, intact, and chemically compatible with the waste. • Cover is of low permeability and is intact. • Leachate collection system is above the liner. • Backup protection is supplied by a double liner with an adequate leakage detection system. • Backup protection is supplied by a ground water monitoring system that is adequate in type, number, and location of devices.	0.1
• Physical containment is adequate, but leakage detection and/or the ground water monitoring system is inadequate.	0.5
• Minor deficiency in the physical containment system; liner is moderately permeable, cover is defective, or no leachate collection.	0.8
• Major deficiency(ies) in the physical containment system; liner is absent, liner is known to be perforated, liner is probably chemically incompatible with the waste.	1.0

Waste containment effectiveness factors for ground water pathways [20]	
Liquid Containing Surface Impoundment	**Score**
• Liner is essentially impermeable, intact, and chemically compatible with the waste. • Backup protection is supplied by a double liner or appropriate leakage detection system. • Ground water monitoring devices are adequate in type, number, and location.	0.1
• Physical containment system is sound, but leakage detection and/or ground water monitoring system is inadequate.	0.5
• Minor deficiency(ies) in physical containment; double liner is moderately permeable or in deteriorating condition.	0.8
• Major deficiency(ies) in physical containment system; liner is absent, liner is known to be perforated, liner is probably chemically incompatible with the waste.	1.0

Waste containment effectiveness factors for ground water pathways [20]	
Non-Liquid Containing Surface Impoundment	**Score**
• Liner is essentially impermeable, intact, and chemically compatible with the waste. • Cover is of low permeability and is intact. • Leachate collection system is above the liner. • Backup protection is supplied by a double liner with an adequate leakage detection system. • Backup protection is supplied by a ground water monitoring system that is adequate in type, number, and location of devices.	0.1
• Physical containment is adequate, but leakage detection and/or the ground water monitoring system is inadequate.	0.5
• Minor deficiency in the physical containment system; liner is moderately permeable, cover is defective, or no leachate collection.	0.8
• Major deficiency(ies) in the physical containment system; liner is absent, liner is known to be perforated, liner is probably chemically incompatible with the waste.	1.0

Waste containment effectiveness factors for ground water pathways [20]	
Spills	**Score**
• Contaminated materials appear to have been removed completely.	0.1
• Contaminated area is covered with impervious material that is expected to prevent further infiltration and leaching.	0.5
• No clean-up action or covering has been done.	1.0

Waste containment effectiveness factors for ground water pathways [20]	
Former Fire Training Area	**Score**
• Contaminated materials appear to have been removed completely.	0.1
• Contaminated area is covered with impervious material that is expected to prevent further infiltration and leaching.	0.5
• No clean-up action or covering has been done.	1.0

Waste containment effectiveness factors for ground water pathways [20]	
Area Fire Training Area	**Score**
• Area is lined with material that is essentially impermeable, intact, and chemically compatible with fuels. • Liner is protected from heat and puncture by an adequate thickness of buffer material (e.g., sand under gravel). • Backup protection is supplied by a double liner or appropriate leakage detection or monitoring system. • Facility is regularly inspected for containment integrity.	0.1
• Containment system is sound but lacks complete backup protection, area has a concrete surface with no double liner or leakage detection system, or there is no regular inspection. • Backup protection exists, but there are minor deficiencies in basic containment; liner is not protected from heat by a buffer layer.	0.5
• Containment system is present, but has potentially significant deficiencies. • Area has a concrete surface without heat protection, a double liner, or a leakage detection system. • Liner materials are now suspected to be chemically incompatible with some fuel constituents.	0.8
• Major deficiencies in the containment system. • Area is unlined. • Liner is a synthetic membrane not protected from puncturing. • Liner is perforated or shows other visible signs of deterioration.	1.0

Waste containment effectiveness factors for ground water pathways [20]	
Waste Pile	**Score**
• Contaminated materials appear to have been removed completely.	0.1
• Contaminated area is covered with impervious material that is expected to prevent further infiltration and leaching.	0.5
• No clean-up action or covering has been done.	1.0

Waste containment effectiveness factors for ground water pathways [20]	
Above Ground Tank	**Score**
• Tanks and piping are in sound condition and are inspected regularly. • Tank area is lined to prevent infiltration to ground water and surrounded by berms.	0.1
• Tanks and piping are in sound condition, but tank area is not lined. • Tank area is bermed and lined to prevent infiltration to ground water, but tanks or piping show signs of deterioration. • There is evidence of past leaks or spills within the lined and bermed area.	0.8
• Tanks or piping are leaking. • Tank area is not adequately lined and bermed and tanks or piping show signs of deterioration. • There is evidence of past leaks or spills in areas not protected by liners and berms.	1.0

Waste containment effectiveness factors for ground water pathways [20]	
Underground Tank	**Score**
• Tanks and piping are double-walled or installed above an impermeable liner. • Interior lining of tanks and piping is chemically compatible with contents. • Outer walls of tanks and piping are of noncorrosible material or cathodically protected from corrosion. • Leakage detection system exists.	0.1
• Tanks and piping are appropriately constructed, but no leakage detection system exists.	0.5
• Some deficiencies in tanks, piping, and/or leakage detection system. • Tank is double-walled and leakage detection system exists, but outer walls are not protected from corrosion. • Tank is double-walled and a leakage detection system exists, but interior lining of tank may not be chemically compatible with tank contents. • Tank is single-walled and not installed above an impermeable liner, but tank material is noncorrosible and chemically compatible with tank contents and there is a leakage detection system.	0.8
• Major deficiencies in physical containment; tank is single-walled not installed above an impermeable liner, and there is no leakage detection system.	1.0

Waste containment effectiveness factors for ground water pathways [20]	
Site within Enclosed Structure	**Score**
• Tanks, piping, containers, etc., are in sound condition and are inspected regularly. • Drainage from hazardous-material handling and storage areas is treated properly and is isolated from the floor drain systems that connect to storm water drainage systems or sanitary sewers. • Any past spills or leaks are cleaned up completely.	0.1
• Tanks, piping, containers, etc. are in sound condition and are inspected regularly. • There is no evidence of past spills or leaks, but drainage from hazardous-material handling and storage areas is not effectively isolated from floor drain systems that connect to storm water drainage systems or sanitary sewers.	0.5
• Tanks, piping, containers, etc., are not in sound condition, visibly corroded or leaking. • There is evidence of past spills or leaks, and drainage from hazardous-material handling and storage areas is not effectively isolated from floor drain systems that connect to storm water drainage systems or sanitary sewers.	0.8

Waste containment effectiveness factors for ground water pathways [20]	
Site with Ground Water Contamination	**Score**
In general, assign a score of 1.0 to signify uncontained contamination in the ground water. If some ground water cleanup has been done, a lower score may be assigned using the guidance below: • Contaminated water is believed to have been removed completely.	0.1
• Containment enclave is physically contained; subsurface cutoff walls attached to low-permeability layers.	0.5
• Contaminant enclave has not been removed or effectively contained.	1.0

Waste containment effectiveness factors for air/soil volatiles pathways [32]	
Uncapped Landfill	**Score**
• Daily cover material is applied.	0.5
• No daily cover material is applied.	1.0

Waste containment effectiveness factors for air/soil volatiles pathways [32]	
Capped Landfill	**Score**
• Landfill is covered with a compacted clay cap which is in good condition. • Barometric pumping of the landfill is vented to VOC control system. • Landfill surface is covered with vegetation to prevent fugitive dust emissions.	0.1
• Landfill is covered with a compacted clay cap which has little or no damage. • Landfill is vented to the atmosphere. • Vegetation cover or a dust suppression system used to prevent fugitive dust emissions.	0.5
• Landfill is covered with a compacted clay cap. • No vegetation or a dust suppression system is present to control fugitive dust emissions.	0.8
• Landfill lacks a clay cap and a soil cover.	1.0

Waste containment effectiveness factors for air/soil volatiles pathways [32]	
Liquid Containing Surface Impoundment	**Score**
• Surface is covered with a synthetic membrane or a clay cap.	0.1
• Impoundment has a wind barrier.	0.5
• Impoundment has a clay cap in poor condition and contains liquid from rainwater.	0.8
• Impoundment has no clay cap or barrier and contains liquid derived from rainwater.	1.0

Waste containment effectiveness factors for air/soil volatiles pathways [32]	
Non-liquid Containing Surface Impoundment	Score
• Impoundment is covered or has a wind barrier.	0.1
• Impoundment is open to the atmosphere.	0.8

Waste containment effectiveness factors for air/soil volatiles pathways [32]	
Spill	Score
• Contaminated area is completely covered by a permanent structure such as a paved surface or building.	0.1
• 50% or more of the contaminated area is covered.	0.5
• Contaminated area is less than 50% covered.	0.8
• No covering of the contaminated area.	1.0

Waste containment effectiveness factors for air/soil volatiles pathways [32]	
Former Fire Training Area	Score
• Contaminated area is completely covered by a permanent structure such as a paved surface or building.	0.1
• 50% or more of the contaminated area is covered.	0.5
• Contaminated area is less than 50% covered.	0.8
• No covering of the contaminated area.	1.0

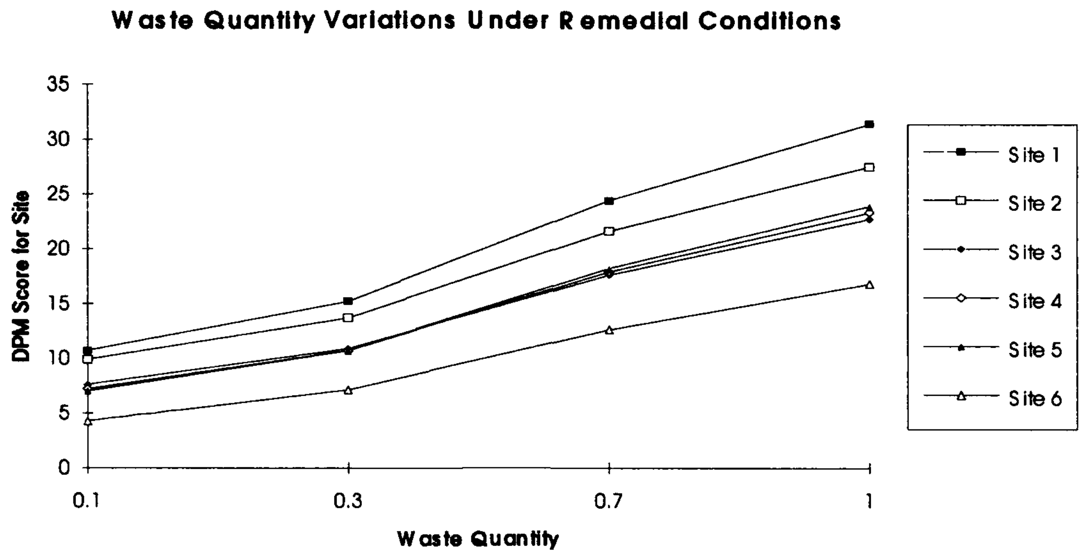
Waste containment effectiveness factors for air/soil volatiles pathways [32]	
Active Fire Training Area	Score
• Contaminated area is completely covered by a permanent structure such as a paved surface or building.	0.1
• 50% or more of the contaminated area is covered.	0.5
• Contaminated area is less than 50% covered.	0.8
• No covering of the contaminated area.	1.0

Waste containment effectiveness factors for air/soil volatiles pathways [32]	
Waste Pile	**Score**
• Waste pile is capped and covered with a physical barrier (e.g., tarp).	0.1
• Waste pile is covered with physical barrier (e.g., tarp).	0.5
• Waste pile is open to atmosphere, no cover used.	1.0

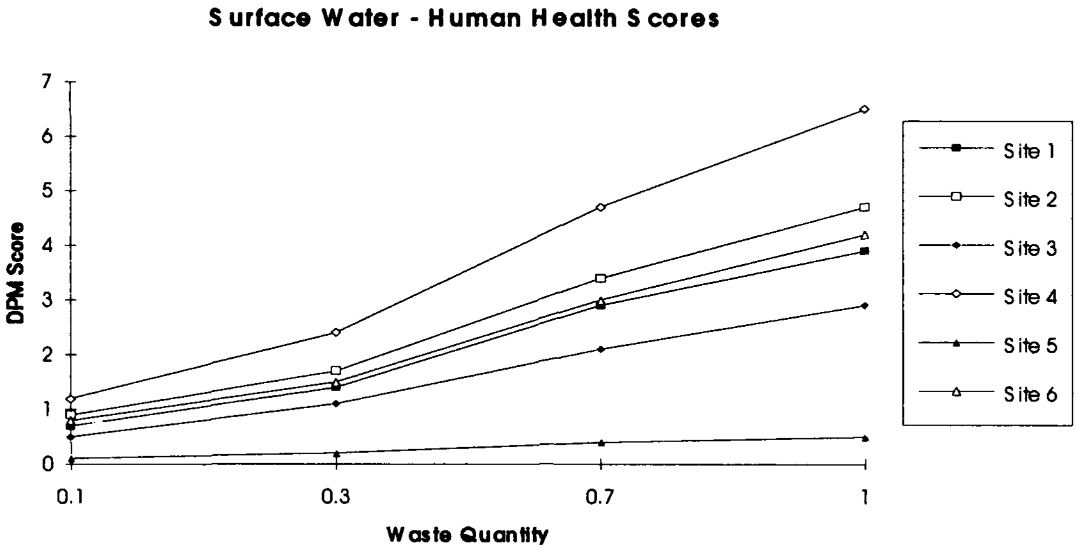
Waste containment effectiveness factors for air/soil volatiles pathways [32]	
Above Ground Tank	**Score**
• Contaminated area is completely covered by a permanent structure such as a paved surface or building.	0.1
• 50% or more of the contaminated area is covered.	0.5
• Contaminated area is less than 50% covered.	0.8
• No covering of the contaminated area.	1.0

Waste containment effectiveness factors for air/soil volatiles pathways [32]	
Underground Tank	**Score**
• Contaminated area is completely covered by a permanent structure such as a paved surface or building.	0.1
• 50% or more of the contaminated area is covered.	0.5
• Contaminated area is less than 50% covered.	0.8
• No covering of the contaminated area.	1.0

Appendix D: Sensitivity Analysis Regression Plots



WQ	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
0.1	10.7	9.9	7.6	7.2	7	4.3
0.3	15.2	13.7	10.9	10.7	10.7	7.1
0.7	24.4	21.6	17.6	17.9	18.2	12.6
1	31.4	27.5	22.7	23.3	23.9	16.8

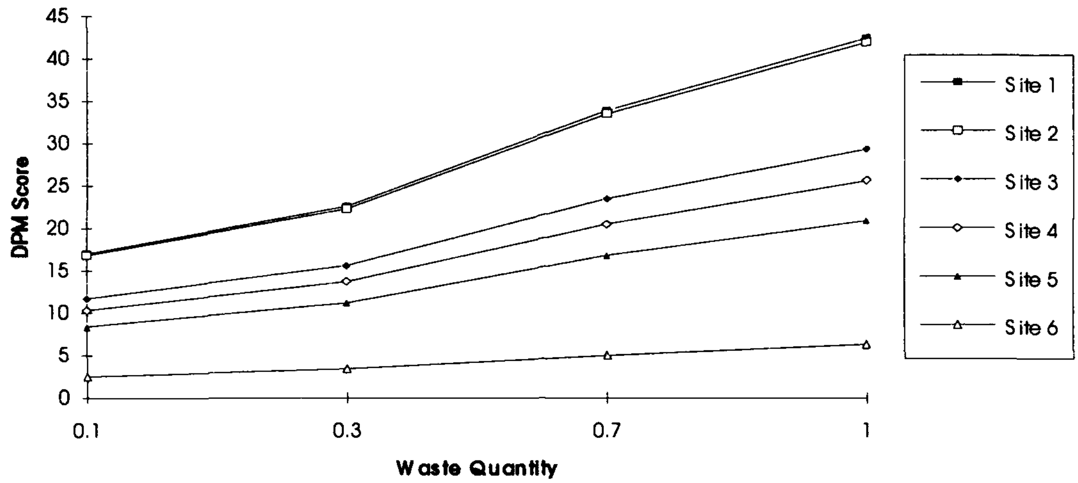


WQ	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
0.1	0.7	0.9	0.5	1.2	0.1	0.8
0.3	1.4	1.7	1.1	2.4	0.2	1.5
0.7	2.9	3.4	2.1	4.7	0.4	3
1	3.9	4.7	2.9	6.5	0.5	4.2

Site 1: $Y = 3.59(X) + 0.34, \sigma = 1.25$
Site 2: $Y = 4.23(X) + 0.45, \sigma = 1.48$
Site 3: $Y = 2.64(X) + 0.27, \sigma = 0.92$
Site 4: $Y = 5.87(X) + 0.62, \sigma = 2.05$
Site 5: $Y = 0.45(X) + 0.06, \sigma = 0.16$
Site 6: $Y = 3.78(X) + 0.39, \sigma = 0.39$

Correlation Coefficient (all sites) $\cong 1$

Groundwater - Human Health Scores



WQ	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
0.1	17	16.8	11.7	10.3	8.4	2.5
0.3	22.6	22.3	15.6	13.7	11.2	3.4
0.7	33.9	33.5	23.5	20.5	16.8	5
1	42.4	41.9	29.3	25.6	20.9	6.3

Site 1: $Y = 28.23(X) + 14.15, \sigma = 9.86$

Site 2: $Y = 27.91(X) + 13.97, \sigma = 9.74$

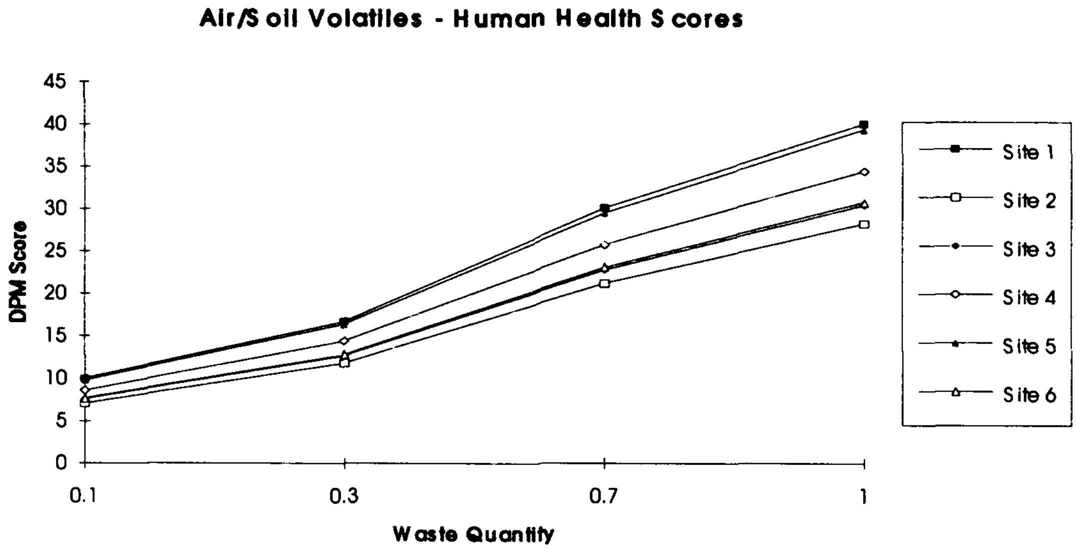
Site 3: $Y = 19.59(X) + 09.74, \sigma = 6.84$

Site 4: $Y = 17.00(X) + 08.60, \sigma = 5.93$

Site 5: $Y = 13.90(X) + 07.03, \sigma = 4.85$

Site 6: $Y = 04.19(X) + 02.10, \sigma = 1.46$

Correlation Coefficient (all sites) $\cong 1$



WQ	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
0.1	10	7.1	7.6	8.6	9.8	7.7
0.3	16.7	11.8	12.7	14.4	16.4	12.8
0.7	30.1	21.2	22.8	25.8	29.5	23.1
1	40.1	28.3	30.5	34.5	39.4	30.8

Site 1: $Y = 33.45(X) + 6.66, \sigma = 11.68$

Site 2: $Y = 23.55(X) + 4.74, \sigma = 8.22$

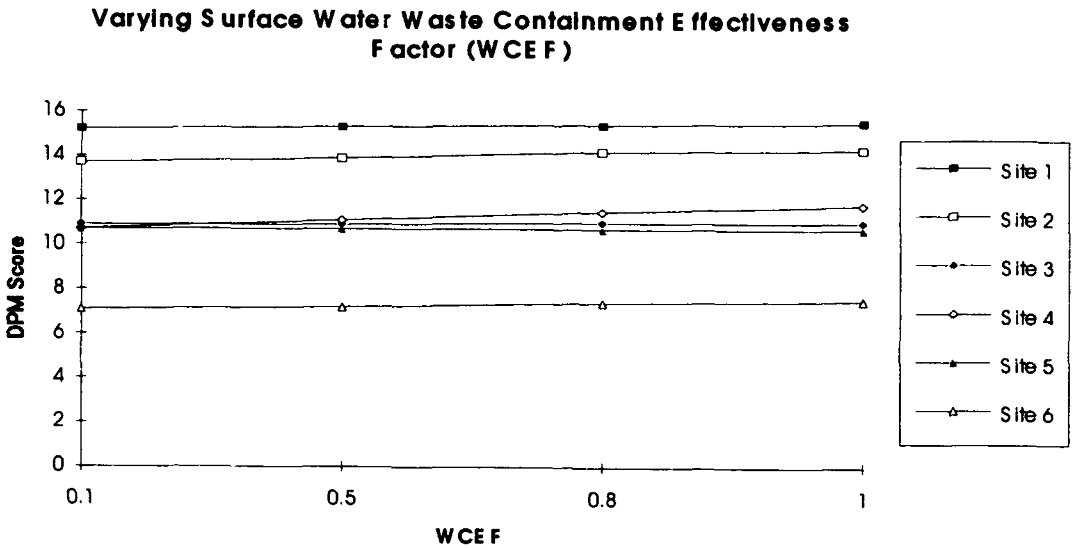
Site 3: $Y = 25.42(X) + 5.06, \sigma = 8.87$

Site 4: $Y = 28.73(X) + 5.74, \sigma = 10.03$

Site 5: $Y = 32.87(X) + 6.52, \sigma = 11.47$

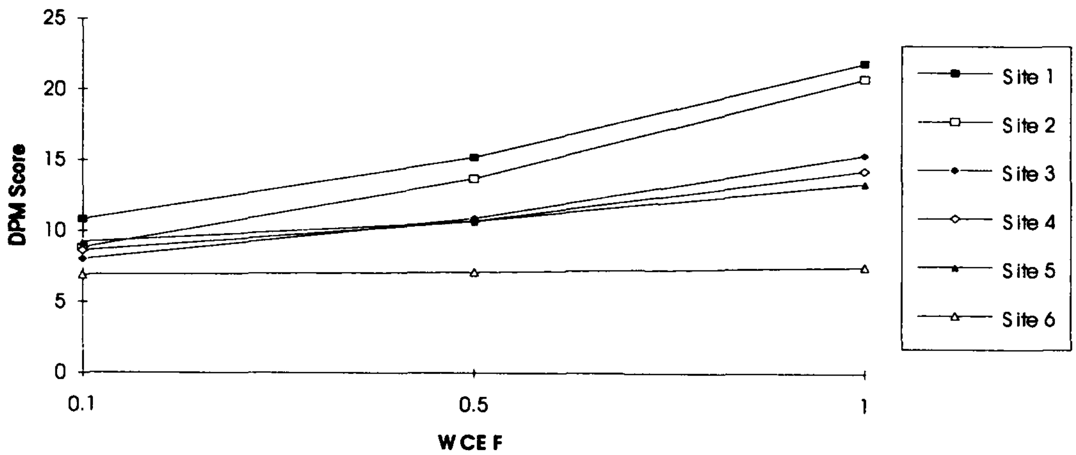
Site 6: $Y = 25.68(X) + 5.12, \sigma = 8.97$

Correlation Coefficient (all sites) $\cong 1$

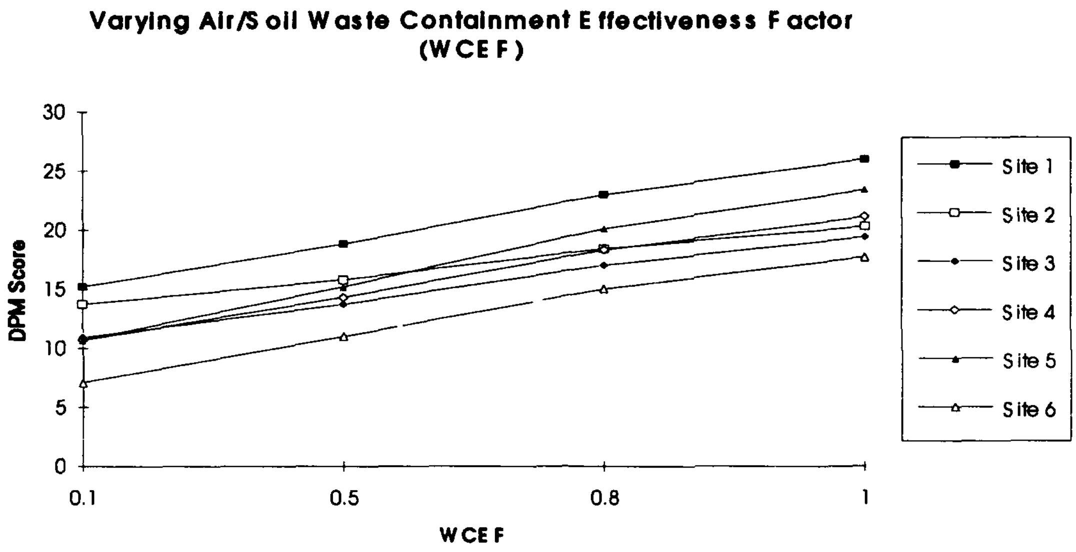


WCEF	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
0.1	15.2	13.7	10.9	10.7	10.7	7.1
0.5	15.3	13.9	10.9	11.1	10.7	7.2
0.8	15.4	14.2	11	11.5	10.7	7.4
1	15.5	14.3	11	11.8	10.7	7.5

Varying Groundwater Waste Containment Effectiveness Factor (WCEF)

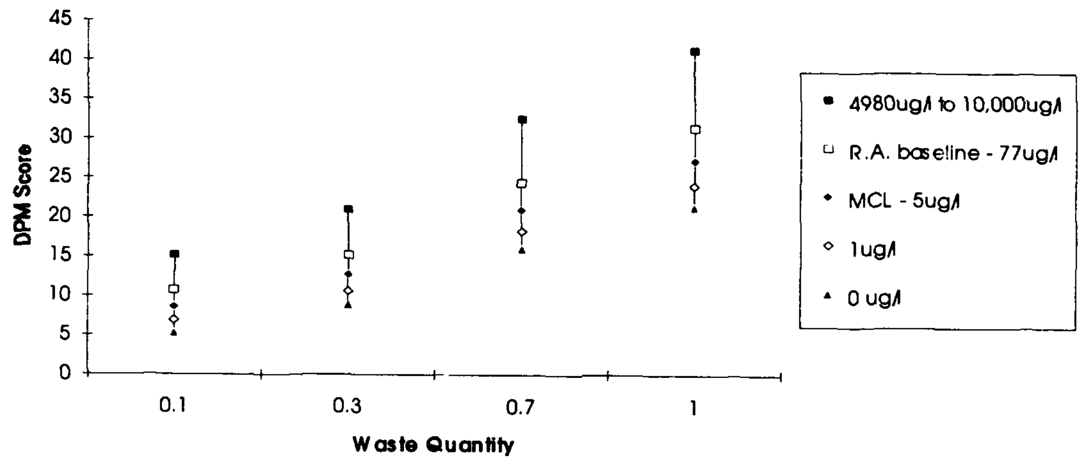


WCEF	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
0.1	10.8	8.8	8	8.6	9.2	6.9
0.5	15.2	13.7	10.9	10.7	10.7	7.1
1	21.9	20.8	15.4	14.3	13.4	7.5

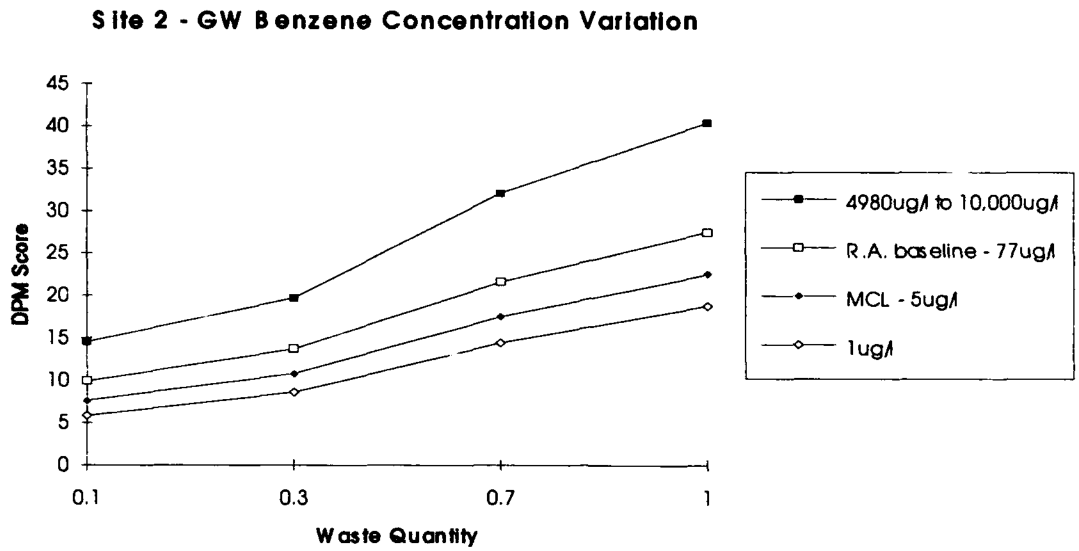


WCEF	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
0.1	15.2	13.7	10.9	10.7	10.7	7.1
0.5	18.8	15.8	13.7	14.3	15.2	11
0.8	23	18.4	17	18.3	20.1	15
1	26	20.3	19.4	21.1	23.4	17.7

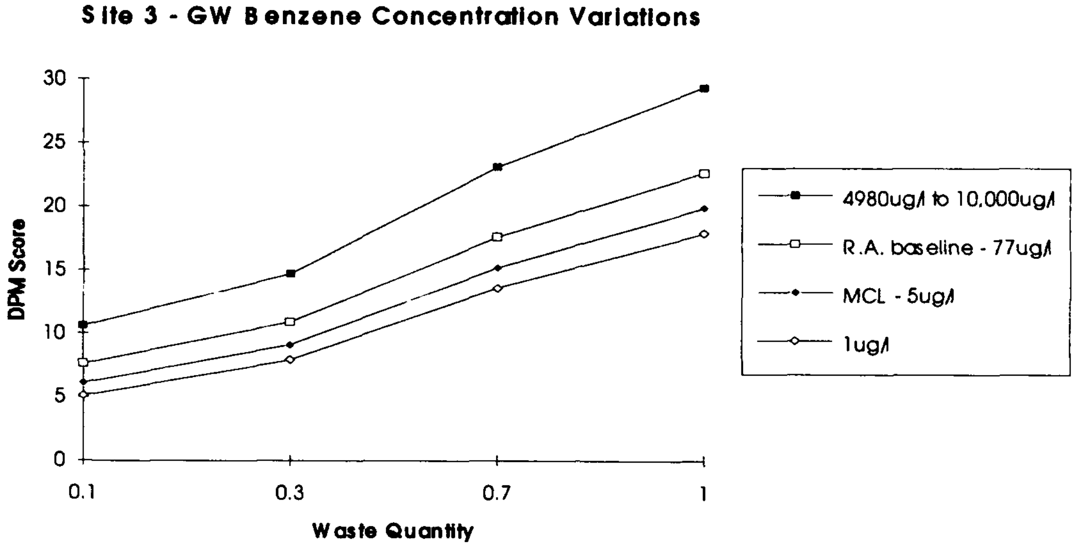
Site 1 - Remedial Action Risk Scores as Groundwater Benzene Concentrations Vary



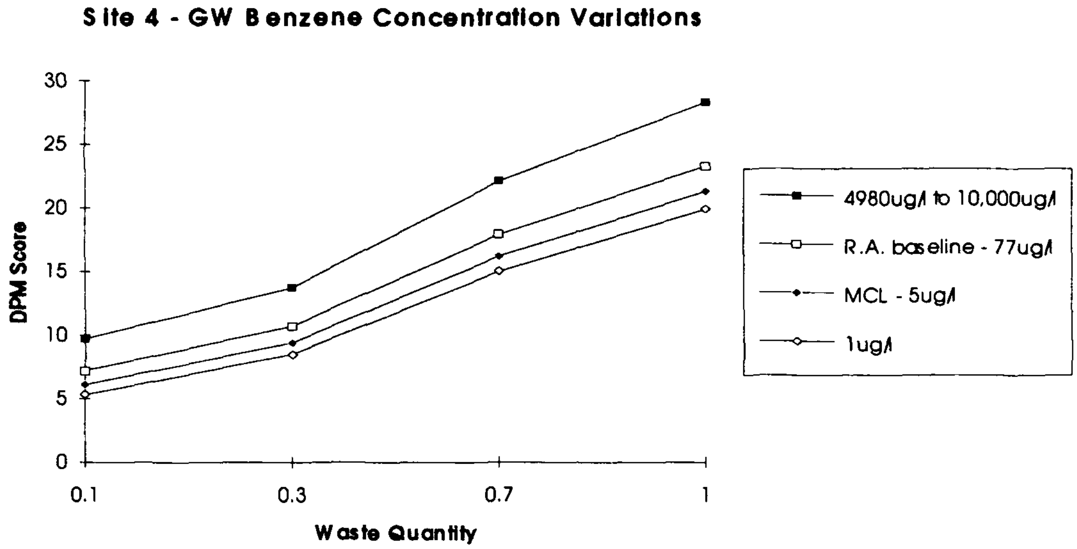
WQ	4980ug/l to 10,000ug/l	R.A. baseline - 77ug/l	MCL - 5ug/l	1ug/l
0.1	15.1	10.7	8.6	6.9
0.3	20.9	15.2	12.7	10.6
0.7	32.5	24.4	21	18.2
1	41.3	31.4	27.2	24



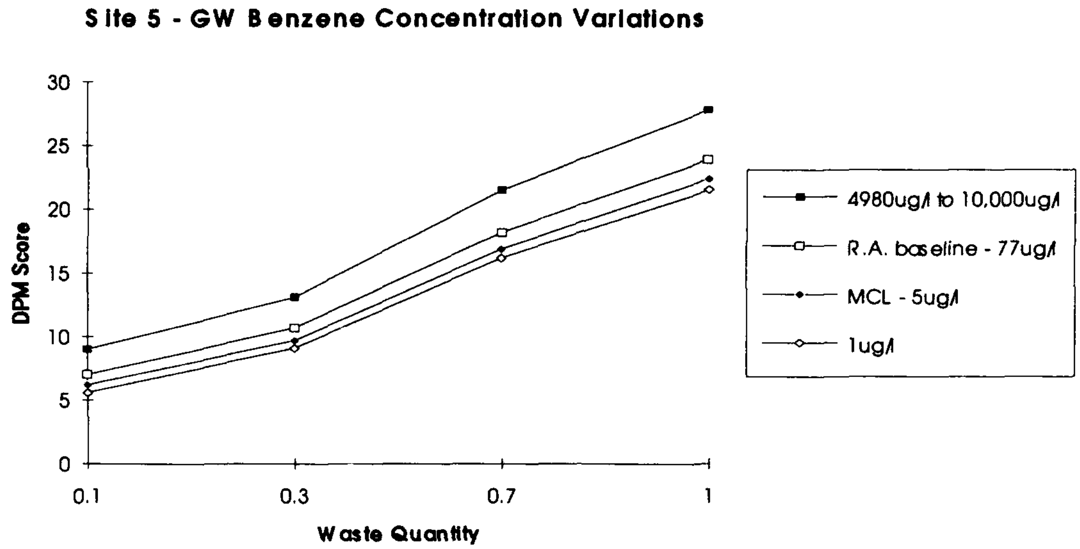
WQ	4980ug/l to 10,000ug/l	R.A. baseline - 77ug/l	MCL - 5ug/l	1ug/l
0.1	14.5	9.9	7.6	5.8
0.3	19.7	13.7	10.8	8.6
0.7	32.1	21.6	17.5	14.4
1	40.4	27.5	22.5	18.8



WQ	4980ug/l to 10,000ug/l	R.A. baseline - 77ug/l	MCL - 5ug/l	1ug/l
0.1	10.6	7.6	6.1	5.1
0.3	14.7	10.9	9.1	7.9
0.7	23.1	17.6	15.2	13.6
1	29.4	22.7	19.9	17.9

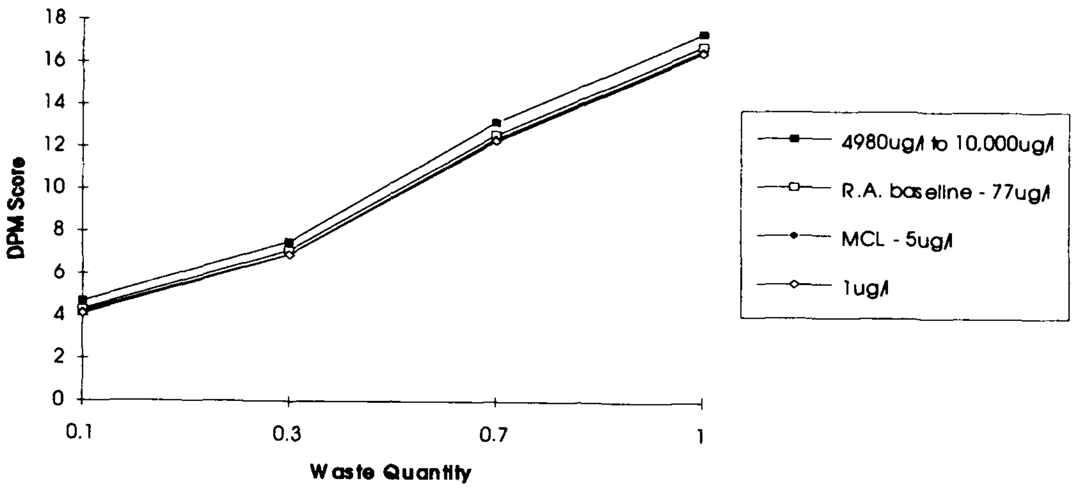


WQ	4980ug/l to 10,000ug/l	R.A. baseline - 77ug/l	MCL - 5ug/l	1ug/l
0.1	9.7	7.2	6.1	5.3
0.3	13.7	10.7	9.4	8.5
0.7	22.1	17.9	16.2	15
1	28.3	23.3	21.3	19.9



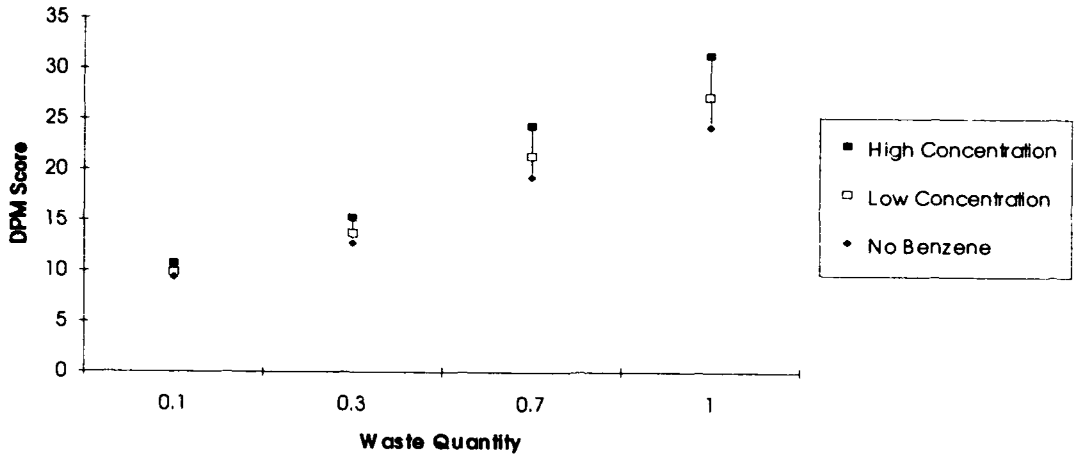
WQ	4980ug/l to 10,000ug/l	R.A. baseline - 77ug/l	MCL - 5ug/l	1ug/l
0.1	9	7	6.2	5.6
0.3	13.1	10.7	9.7	9.1
0.7	21.5	18.2	16.9	16.2
1	27.8	23.9	22.4	21.5

Site 6 - GW Benzene Concentration Variations

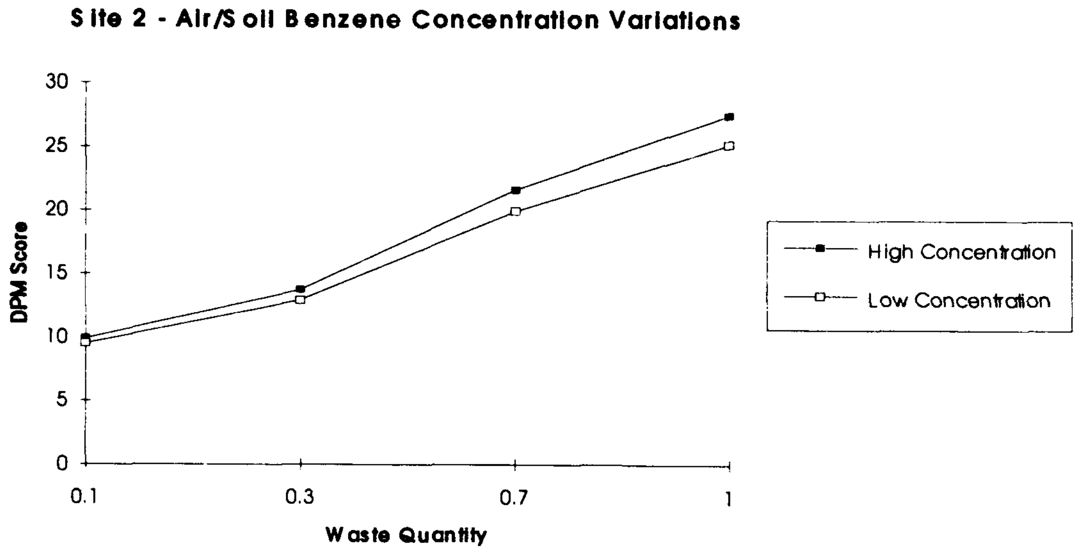


WQ	4980ug/l to 10,000ug/l	R.A. baseline - 77ug/l	MCL - 5ug/l	1ug/l
0.1	4.7	4.3	4.2	4.1
0.3	7.5	7.1	6.9	6.9
0.7	13.2	12.6	12.4	12.3
1	17.4	16.8	16.6	16.5

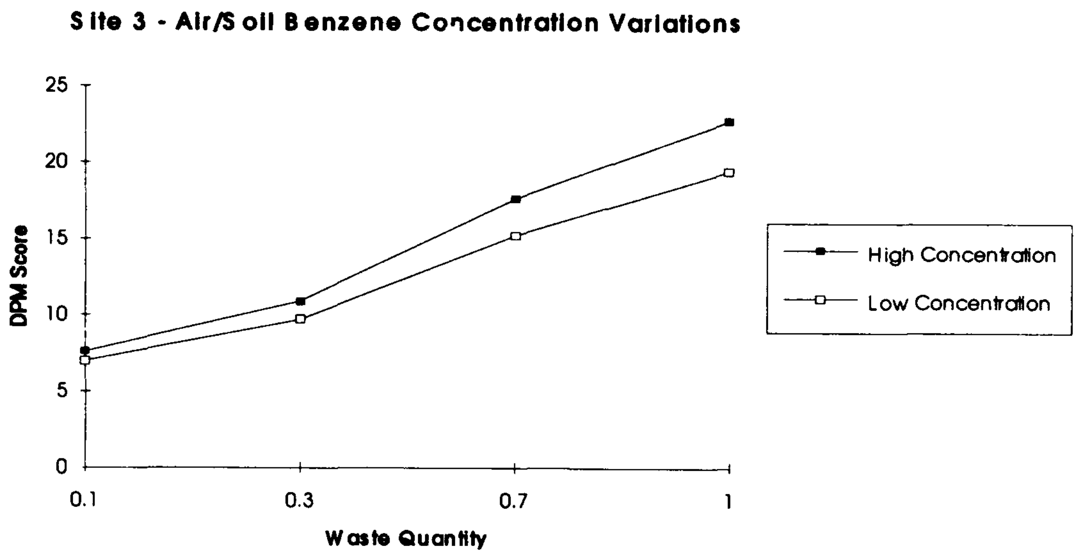
Site 1 - Remedial Action Risk Scores as Air/Soil Volatile Benzene Concentrations Vary



WQ	High Concentration	Low Concentration
0.1	10.7	9.9
0.3	15.2	13.7
0.7	24.4	21.4
1	31.4	27.2

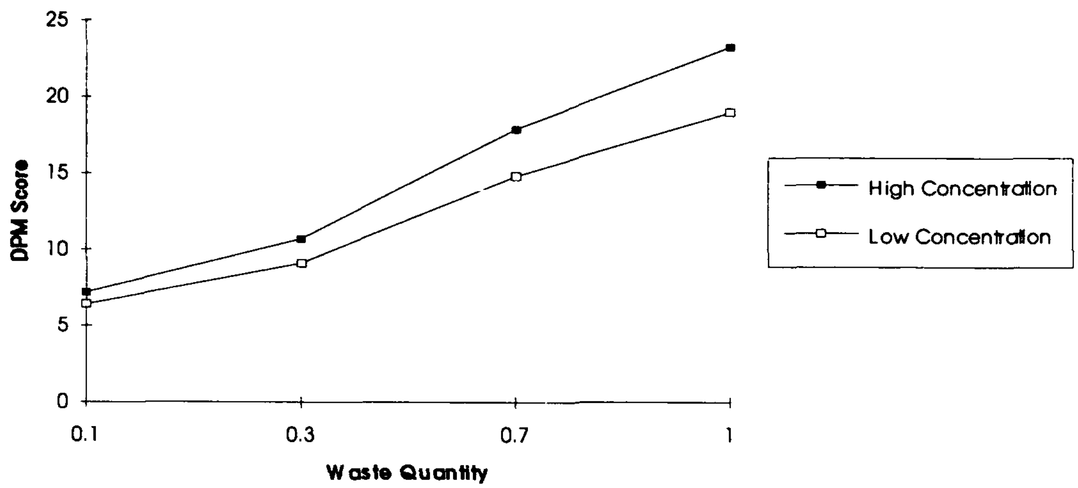


WQ	High Concentration	Low Concentration
0.1	9.9	9.5
0.3	13.7	12.9
0.7	21.6	19.9
1	27.5	25.2

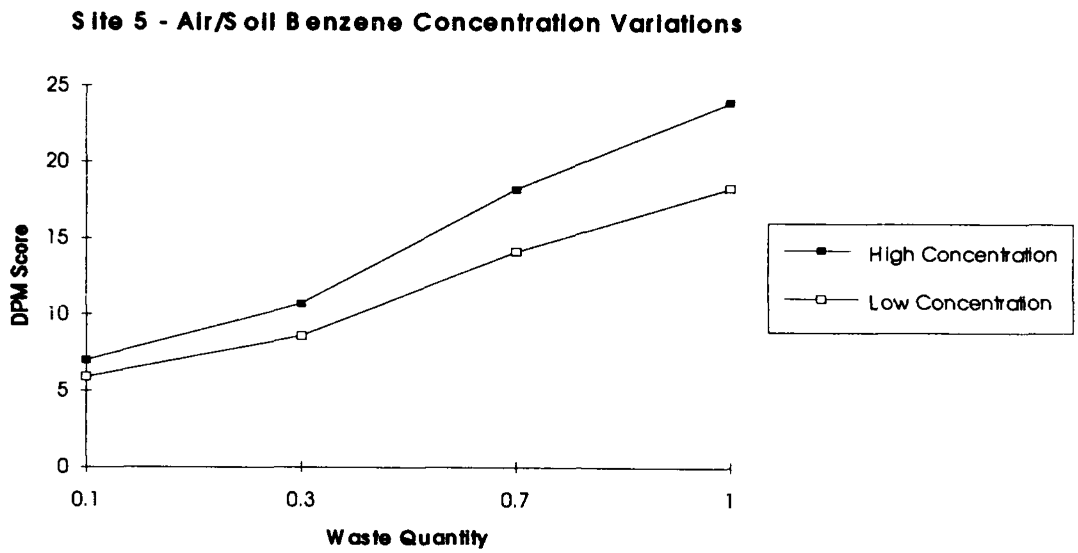


WQ	High Concentration	Low Concentration
0.1	7.6	7
0.3	10.9	9.7
0.7	17.6	15.2
1	22.7	19.4

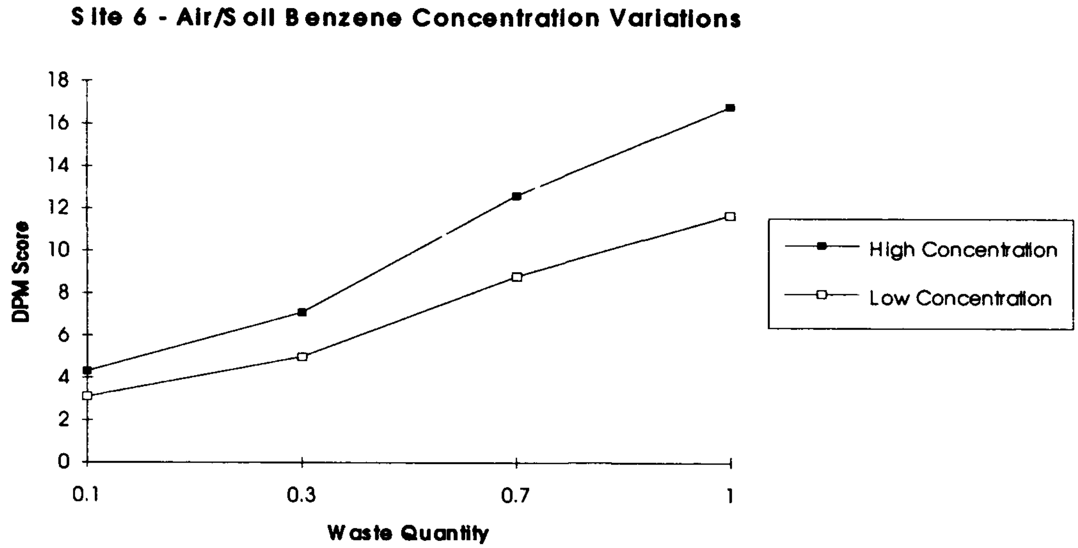
Site 4 - Air/Soil Benzene Concentration Variations



WQ	High Concentration	Low Concentration
0.1	7.2	6.4
0.3	10.7	9.1
0.7	17.9	14.8
1	23.3	19



WQ	High Concentration	Low Concentration
0.1	7	5.9
0.3	10.7	8.6
0.7	18.2	14.1
1	23.9	18.3



WQ	High Concentration	Low Concentration
0.1	4.3	3.1
0.3	7.1	5
0.7	12.6	8.8
1	16.8	11.7

Vita

Timothy L. Fuller was born on 27 May 1967 in Sioux Falls, South Dakota. He graduated from Lincoln Senior High School located in Sioux Falls in 1985. He then attended Iowa State University where he received the degree of Bachelor of Science in Engineering Operations in May 1990. Upon graduation and commissioning as a Second Lieutenant in the United States Air Force, he held the position of Chief, Industrial Engineering Flight at F.E. Warren AFB, Wyoming from January 1991 to May 1992. From June 1992 to May 1993, he held the position of Chief of Resources Flight, Kunsan Air Base, Republic of Korea, where he was responsible for the squadron automation systems, manpower, real property management, and financial resources. In 1992 he was selected to attend the Class of 1994 Graduate Engineering and Environmental Management Program at the Air Force Institute of Technology's School of Engineering.

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13. ABSTRACT (Maximum 200 words)

To properly manage the Installation Restoration Program (IRP) in the future, Air Force remedial project managers (RPMs) need a metric to assist in the selection of remedial alternatives for the safe and effective clean up of waste contamination sites. If the baseline site risk assessment indicates that it is necessary to remediate a waste contamination site, it is important to the RPM that the selection process for remediation alternatives considers the potential human health and ecological risks associated with the proposed remediation process. In some instances, the risks may be significant when compared to the baseline conditions.

The Air Force currently uses the Defense Priority Model (DPM) to assist in setting priorities for funding remedial actions based on the relative risk at IRP sites. This study investigates the applicability of the DPM to calculate the relative risks that would be associated with the remedial alternatives under consideration for remediation of the contamination site characteristics. Rescoring the DPM to represent relative risk of a site under remedial action conditions demonstrates that three factors influence the risk value of a remedial action: waste quantity, waste containment effectiveness factor (WCEF), and waste concentration. Limits of the WCEF made it impossible to discern relative risk between similar remedial alternatives. Furthermore, for all cases of contamination sites under remedial conditions, the relative risk of the remedial action was less than the reduction in baseline relative risk due to the improvement in waste containment.

14. SUBJECT TERMS
Defense Priority Model, Relative Risk, Remedial Alternatives

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